NASA CONTRACTOR REPORT

NASA CR-1206

NASA CR-12

PRELIMINARY EVALUATION TEST OF THE LANGLEY CARDIOVASCULAR CONDITIONING SUIT CONCEPT

by W. V. Blockley and S. L. Friedlander

Prepared by
WEBB ASSOCIATES
Malibu, Calif.
for Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1968

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Prepared under Contract No. NAS 1-6004 by
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF TABLES

PRELIMINARY EVALUATION TEST

OF THE

LANGLEY CARDIOVASCULAR CONDITIONING SUIT CONCEPT

By W. V. Blockley

and

S. L. Friedlander

Webb Associates (California)

SUMMARY

Two experiments were conducted, each two weeks in duration, in which the same subject spent the major portion of each day immersed in water and the remainder of the time in bed. For 14 days in each case the man remained completely horizontal except when submerged. In the control experiment, a simple waterproof garment was worn over ordinary long underwear during water immersion; in the second experiment the man was dressed in a specially constructed pressure suit designed to prevent or retard the deconditioning of weightlessness (cardiovascular conditioning suit or CVCS). A full pressure helmet with neck ring was worn in both control and CVCS experiments, and steps were taken to preclude the negative-pressure breathing which is common with ordinary SCUBA gear.

The cardiovascular conditioning suit successfully prevented the deterioration in orthostatic tolerance, impairment in tolerance for brief mild exercise and reduction in maximum work capacity which had been observed in the control experiment, although it was pressurized for only 2 to 4 hours per day from the 6th through 14th days of the experiment. During the initial 5 days, when pressurization time in the suit was less than one hour per day, venous compliance increased roughly 2-fold, but had fallen again to the initial value by the morning of the 11th day.

Venous compliance appears to be an excellent predictor of tilt-table response. In the control experiment it increased 3-fold during the 14 day exposure to bed-rest and immersion; the post-exposure tilt to 70° was terminated in pre-syncope at 11 minutes. In the experiment in which the CVCS was used there was essentially no difference in venous compliance between pre- and post-exposure, and the tilt responses were the same except for a slight elevation of diastolic pressures during the post-exposure tilt.

INTRODUCTION

Under the terms of contract NAS1-6004, Webb Associates undertook the development and fabrication of a special-purpose pressurized garment designed to meet performance requirements laid down by the Langley Research Center of NASA. In essence, the suit is intended to apply external pressure to the body by means of a series of toroidal compartments or bladders enclosing contiguous sections of each limb and the torso. Each compartment or torus is from 2 to 4 inches in width, and the pressure in each is proportional to the height above the ground (in an erect man) of the center of that portion of the body. When the suit is fully pressurized the uppermost torus of the torso and shoulder area exerts a pressure equivalent to the hydrostatic head of a column of water roughly equal to the height of an erect man's heart above the ground and the pressures in all other compartments of the suit are progressively less than the foregoing value,by an amount equal to the distance of each below heart level.

To enable continuous pressurization of such a suit, it is necessary to provide means for pressurizing the lungs by an amount sufficient to counter-balance the external pressure on the chest. Consequently, the system incorporates a specially designed full-pressure helmet mounted on a neck-ring attached to the suit, supplied by a positive-pressure demand regulator and equipped with a servo-assisted, pressure compensated exhalation valve.

The purpose of the cardiovascular conditioning suit, as defined by the NASA specification, is to set up a transmural pressure gradient in the circulatory system, while weightless, similar to that which exists in the erect posture at 1G. The objective was to determine if this pressure gradient would have a beneficial effect in preventing deconditioning of the vascular system during a period of prolonged weightlessness. Figure 1 compares schematically the transmural pressure gradient of the circulatory system of a man erect at 1G with that observed when wearing the pressurized cardiovascular conditioning suit (CVCS) while immersed in water. The transmural pressure at any point is the algebraic sum of the breathing pressure, transmitted to the circulatory system in the intrathoracic cavity, the blood pressure, the internal and external hydrostatic heads and the external loading of the CVCS. Notice that in immersion, the internal and external hydrostatic heads will always be equal regardless of the relative position in the water of the body, and since the breathing pressure is referenced to the water depth neither position or depth will alter the transmural pressure gradients. In the diagrams, all pressures are referenced to the local ambient pressure at chest level.

The design of the CVCS ensures that transmural pressures throughout the venous system will equal, when the suit is pressurized, those which would be found in an erect man at 1G (when his venous valves are ineffective). While this matching of transmural pressures is the basis of the anti-deconditioning action of the suit, it is important to remember that in the weightless or immersed state there are no hydrostatic heads, irrespective of the internal pressure gradients which might exist under various circumstances. Consequently, in the recumbent, water-immersed or weightless states, the pattern of transmural pressures created by the suit should not interfere with blood flow in the manner which characterizes the normal 1G, unsuited condition.

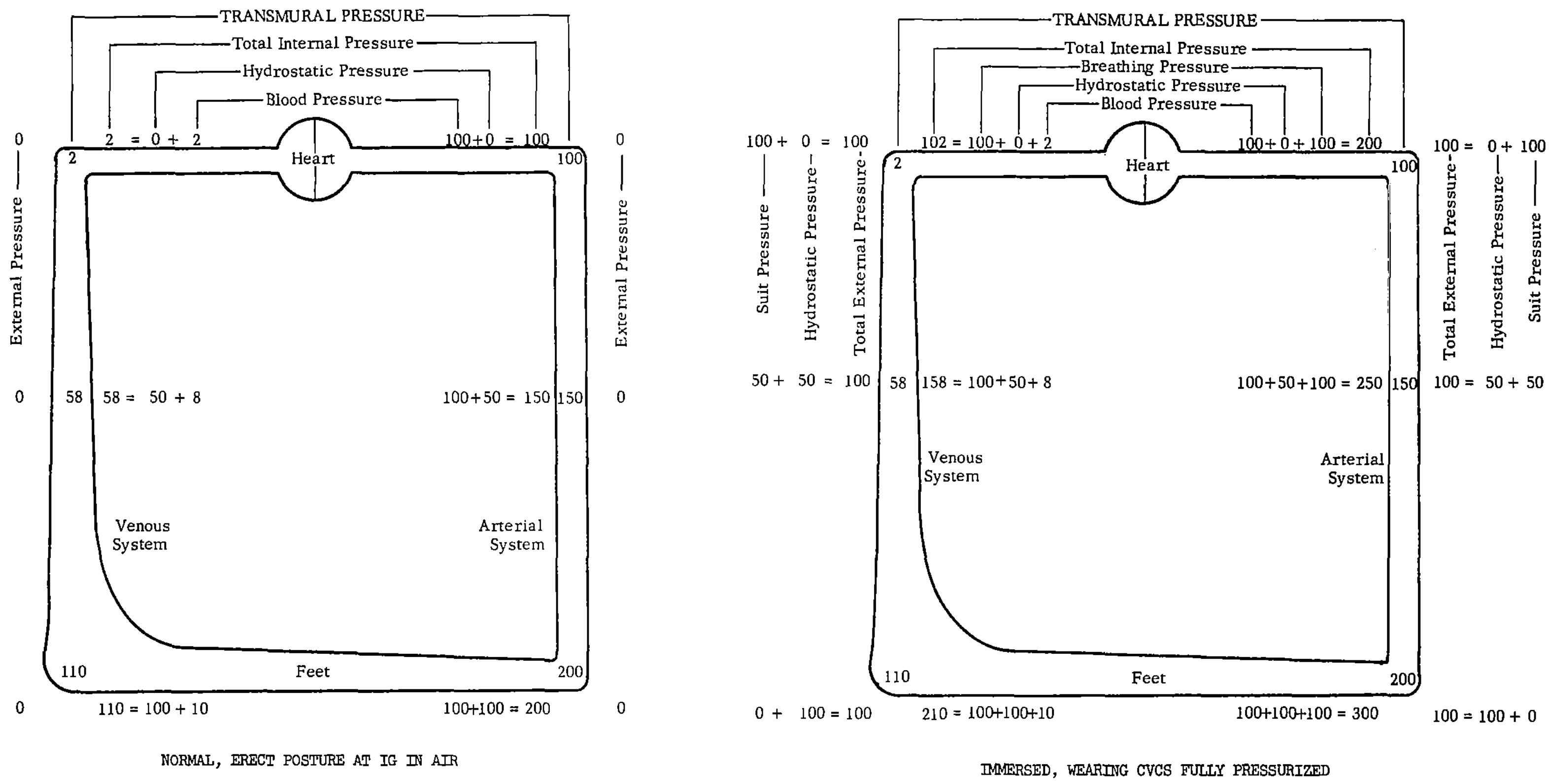


Figure 1: DUPLICATION OF NORMAL TRANSMURAL PRESSURES BY THE CVCS, Illustrated by a Simplified Model of the Vascular System

OVERALL TEST PLAN

The basic outline of the test, as specified by NASA, was to use one subject as his own control to determine the magnitude of the effect, if any, of wearing the CVCS periodically during a 2-week period of combined bed-rest and water immersion. To provide a base-line reference, a control experiment was performed initially, in which the subject was exposed to the "hypodynamic" environment for two weeks without the use of the CVCS. After an interval of 10 weeks, during which the subject was presumed to have recovered from the deconditioning, the subject was again exposed to two weeks of continuous bed-rest and immersion, this time wearing the CVCS during the immersion periods. The effect of the suit was evaluated by a comparison of the relative magnitudes of the change in physiological condition at the end of the two 2-week experiments. The dates and corresponding experiment days for both experiments are listed in Table 1 below. Because the second two-week period (suited experiment) began at 3:30 in the afternoon, there are 15 exposure days although the total duration was fourteen 24-hour periods.

TABLE 1

EXPERIMENT DATES AND IDENTIFICATION CODE

Control Experiment			CVCS Experiment		
Date		Day #	Date		Day #
2/28	First Immersion Day	1	5/22	First Immersion Day	1*
3/1	Second " "	2	5/23	Second " "	2
3/2	Third " "	3	5/24	Third " "	3
3/3	Fourth " "	4	5/25	Fourth " "	4
3/4	Fifth " "	5	5/26	Fifth " "	5
3/5	Sixth " "	6	5/27	Sixth " "	6
3/6	Seventh " "	7	5/28	Seventh " "	7
3/7	Eighth " "	8	5/29	Eighth " "	8
3/8	Ninth " "	9	5/30	Ninth " "	9
3/9	Tenth " "	10	5/31	Tenth " "	10
3/10	Eleventh " "	11	6/1	Eleventh " "	11
3/11	Twelfth " "	12	6/2	Twelfth " "	12
3/12	Thirteenth " "	13	6/3	Thirteenth " "	13
3/13	Fourteenth " "	14	6/4	Fourteenth " "	14
			6/5	Fifteenth " "	15
3/14	First Recovery Day	R_1	6/6	First Recovery Day	R_1
3/15	Second Recovery Day	R_2	6/7	Second Recovery Day	R_2
3/16	Third Recovery Day	R_3	6/8	Third Recovery Day	R_3

*partial day only, starts 15:30

Note: Immediate post-immersion tests were performed at the end of the 14th and 15th immersion days respectively in the control and CVCS experiments.

EXPERIMENTAL PROCEDURES

Before and after each two week experiment the cardiovascular responsiveness of the subject was assessed by means of the tilt-table test, his work capacity was measured by means of a bicycle ergometer test, and the vascular tone was assessed by measuring the venous compliance. After the control experiment, and before as well as after the suit experiment, a test was administered to assess the cardiac response to brief, mild exercise. Pulse wave velocities were measured and vector impedance cardiograms were taken periodically to see if these functions would help in the understanding of de-conditioning and its prevention.

Tilt test.--In reviewing the literature it was noted that some authors preferred to use moderate degrees of inclination, presumably with a view to minimizing the probability of syncope in their subjects. For example, Torphy (ref. 1) used 44°, 53°, and 64°, all for 15 minutes. Goldman (ref. 2) used 60° tilt for 30 minutes, using footboard support, while various other workers have used 70°. In designing the tilt table for use in these experiments provision was made for two tilt angles, 45° and 70°.

Although the ability of the subject to tolerate a 70° tilt without displaying symptoms of hypotension was established well before the experiments began, the pre-immersion tilt test was conducted partly at 45°, but when heart rate and blood pressure returned to their original baseline values at the end of 23 minutes it was decided to increase the angle to 70° without further delay; the larger angle was maintained for a further 15 minutes.

At the end of the 2 week control exposure to a hypodynamic environment a decision had to be made as to the protocol for the tilt test to be performed immediately following removal from the water tank on the final day. After discussion with the technical monitor, it was decided to use a 20 minute tilt at 70°, on the grounds that this was more nearly a standardized procedure, and therefore the results would be more easily interpretable in terms of the work of others. In making this decision the pros and cons of altering the protocol from that which had been used at the beginning of the experiment were weighed against the supposed advantages of adopting a "standard" procedure. As it turned out, the original protocol, beginning with a 45° tilt, would probably have been more desirable, since syncope was encountered half way through the 70° tilt. Having adopted the 70° tilt as standard at the end of the control experiment, a 20 minute duration at this angle was used for both pre-immersion and post-exposure tilts in the CVCS experiment. In Figure 2 is a photograph of the subject during the post-immersion tilt after the CVCS experiment.

Ergometer tests.--The protocol adopted for the pre-immersion test of work capacity in the control experiment was based upon the technique originally developed by Bruno Balke, and used in the early astronaut selection procedure at the USAF School of Aerospace Medicine (ref. 3). The Balke test is done on the treadmill, speed and/or grade being increased every three minutes until the subject quits due to exhausion. In adapting the procedure to the bicycle ergometer, we tried to select a load-time history which would produce exhaustion in about 20 minutes including a 5 minute warmup. In duplicating the ergometer work profile in the post-exposure test, however, we had some misgivings about the apparently large fatiguing effect of so long a session in a de-conditioned individual, even though the subject seemed to tolerate the experience reasonably well, showing a performance which was only slightly inferior in duration and peak work level to that in the pre-immersion test. Therefore, in planning the ergometer test for the CVCS experiment it was decided to attempt to minimize the fatigue factor by eliminating most of the warmup and all of the next three work load steps, going directly to 150 watts after 1 minute at 50. See Figure 2 for a general view of the bicycle ergometer set-up.

Brief exercise test. --Early in the recovery period of the control experiment, it was observed by the subject that walking up a flight of stairs caused an unusual acceleration of the pulse rate. A controlled experiment was devised on the spur of the moment to document this observation, and from this experiment a protocol evolved which was standardized for use in the pre-exposure, post-immersion and recovery periods of the CVCS experiment.

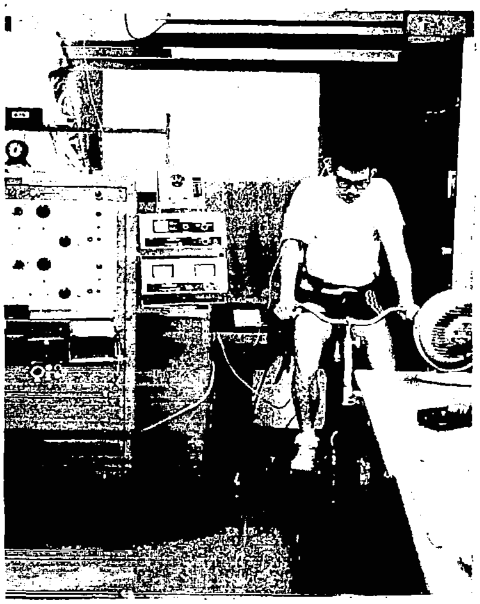
In this test the subject stood for several minutes at the foot of the staircase leading to the top of the 16-foot water tank, then on command began walking up the stairs at a controlled pace, governed by a stop watch which he carried in his hand. He paused at the first flight landing for 6 seconds, after climbing 14 steps in 6 seconds, then climbed the remaining 10 steps in a further 6 seconds; after a rest pause of 6 seconds, he descended both flights without a stop in 6 seconds and immediately repeated the cycle. (See photograph in Figure 2.) Thus in one minute the man climbs 48 steps 8 inches in height and descends the same number, alternating two periods of positive work with two of negative work, ending at ground level, standing at rest, where he began. The timing was made simple by the use of a decimal-minute stop watch, whose main markings occur at 6 second intervals.

This test, with a basic work/rest schedule of 6 seconds on, 6 seconds off, would in a normally healthy person be a relatively moderate exercise load, even if repeated many times. The overall average oxygen cost for the full minute, interpolated from the data at higher and lower work rates in ref. 4 is estimated to be about 1.4 l/min. Bartlett (ref. 5) estimates the average oxygen cost of the double Masters two-step test, which lasts for 3 minutes, as 1.33 l/min. Thus our up-down stair climbing test lasting one minute is slightly easier than a single Masters and considerably easier than the double Masters, partly because of the shorter duration, and partly because of the inclusion of four rest-pauses of 6 seconds each.

Activity. --During the two-week periods of hypodynamic exposure the subject was never permitted to deviate from a horizontal posture except when immersed in the water. Each morning he was rolled from his bed to a wheeled stretcher which was adjustable in height. He was dressed on this stretcher by the experimenter team and then transferred to a litter positioned at the base of a 16-foot water tank. The general test site layout can be seen in Figure 3. The litter was hoisted to the top of the tank where the helmet and breathing system were attached. The litter was then lowered into the water after the necessary connections had been made for instrumentation and communication purposes. In the suited experiment, the final donning of the CVCS itself was completed in the water, with the dressers standing chest deep in the water and the helmeted subject floating between them.

End of the day's immersion. Dry suit being removed. Weighing is next.

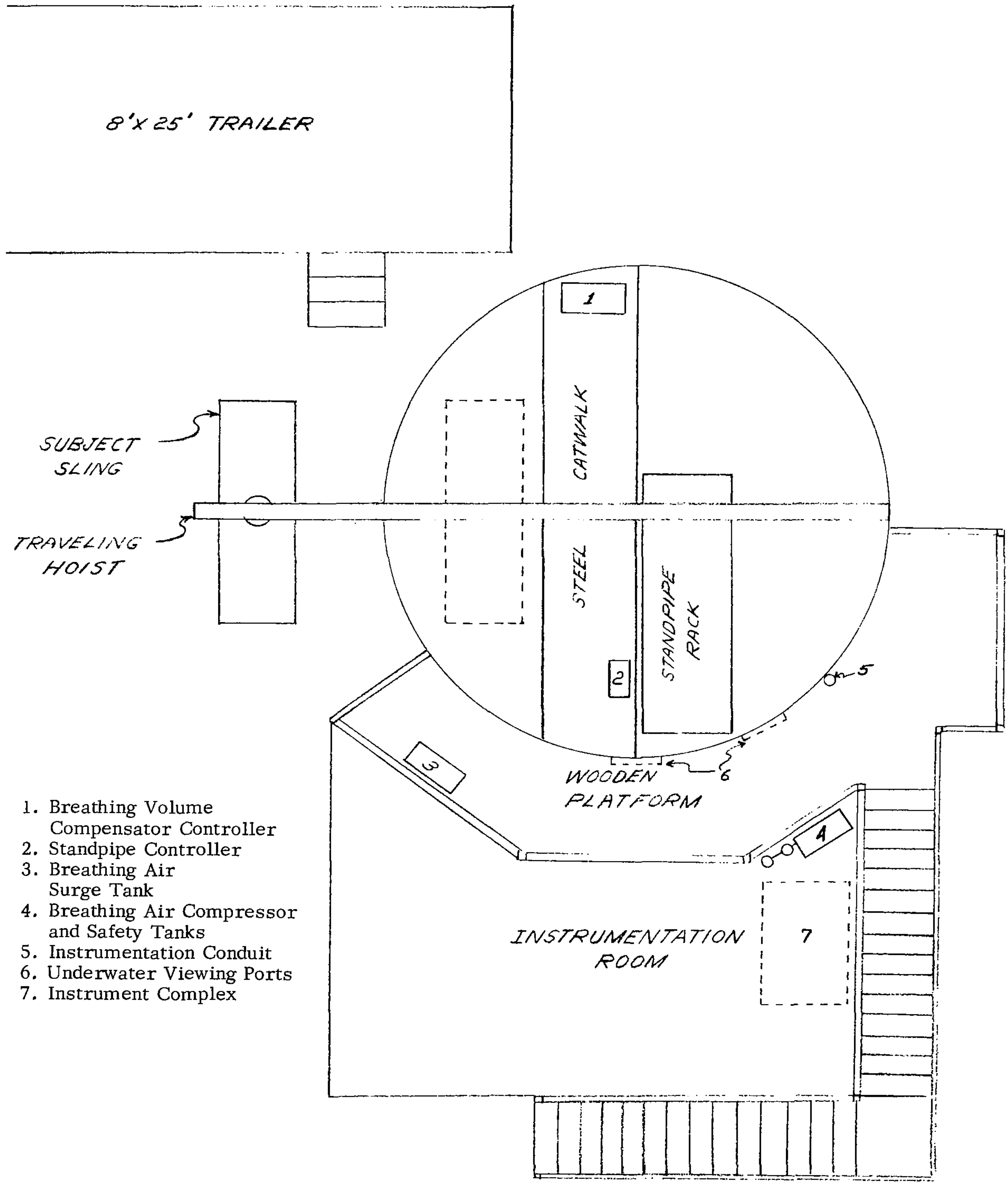
Post-exposure tilt test CVCS experiment; end of 15th immersion day.



Bicycle ergometer and associated instrumentation.

Brief mild exercise test. Subject climbs and descends 2 flights twice in 1 minute.

Figure 2: PHOTOGRAPHIC VIEWS: UNDRESSING OPERATION, TILT TEST, BICYCLE ERGOMETER AND STAIRWAY CLIMB TEST



1. Breathing Volume Compensator Controller
2. Standpipe Controller
3. Breathing Air Surge Tank
4. Breathing Air Compressor and Safety Tanks
5. Instrumentation Conduit
6. Underwater Viewing Ports
7. Instrument Complex

Figure 3: CVCS UCLA TEST SITE, PLAN VIEW

At the end of the day the subject was hoisted from the water on the litter, the helmet was removed and the litter was lowered to the ground. The subject was rolled onto the rolling stretcher, undressed, weighed, bathed and returned to bed.

All meals were eaten in the horizontal position, a tray being placed slightly below bed level with the subject prone. A toilet litter was specially constructed from a canvas camp cot with a folding camp toilet of the disposable plastic bag type. A hole was cut in the canvas cot, permitting the subject to remain supine. Standard hospital urinals were used.

Careful records were kept of all fluids ingested and all urine voided. Twenty-four hour collections of urine were analysed for calcium and creatinine, and routine urinalyses were performed daily. Periodic blood samples were taken and analysed. Food was as close to normal eating habits of the subject as could be practically arranged; breakfast was a normal one, usually citrus juice, eggs, meat, toast and coffee. Lunch invariably consisted of a sandwich and milk or coffee. Dinners were standard frozen meals, usually of the larger, more elaborate type. All food was weighed and recorded in detail.

Medical surveillance. --Each morning of both experiments, the subject was examined by the team physician, chief resident in cardiology at a nearby hospital, and pronounced fit for the day's submersion. The doctor also supervised the tilt-table and exercise tests at the termination of each experiment and followed the subject's condition during the first week after each experiment. Before the first (control) experiment the subject received a complete physical examination with electrocardiographic evaluation and chest X-rays; there were no unusual findings.

PHYSIOLOGICAL MEASUREMENTS

The electrocardiogram was monitored continuously on an oscilloscope before, during and after both two week experiments and during most of the tilt and exercise tests. Silver electrodes were located below the left nipple and on the upper right chest one inch from the mid-line. Signal conditioning and amplification was done by a miniature battery-operated bio-telemetry transmitter (Biolink, Biocom Inc.). This minimized the shock hazard and obviated the necessity of having wires running to the subject during the exercise tests. Recordings were made frequently on a Sanborn Oscillograph.

The following measures were derived from the R - R interval of the EKG: (a) average heart rate, which was displayed on a relatively fast-response meter; (b) beat-to-beat interval which was recorded on the oscillograph; (c) actual counts for selected intervals which were read from electric counters.

The venous compliance was taken before and after each experiment. Because of the very large change noted in this measurement after the control experiment, frequent readings were also taken during the course of the CVCS experiment while the subject was in bed. This measurement was taken in the manner described by Newberry and Bryan (ref. 6) except that a range of 0-60 mm Hg venous flow impeding pressure was used instead of 0-30 mm Hg. In this technique the capacitance vessels are drained by holding the arm elevated with the weight supported on the bony prominences of the wrist and elbow such that there is no compression of the soft tissues. A Whitney mercury-in rubber strain gauge was placed around the forearm at the point of maximum girth, connected to a Parks Model 270 Impedance Transducer and the girth changes recorded on a servo pen recorder. Calibration, in millimeters, was done on the arm with the precision tension screw provided on the Whitney gauge. Complete draining was noted when the forearm circumference, as measured by the gauge reached a steady-state plateau. A venous occlusion pressure of 60 mm Hg was then applied above the elbow with a standard blood pressure occluding cuff and read on a mercury manometer. This pressure was held until a new steady-state circumference was obtained. Pressure was then reduced in 10 mm Hg increments back to zero, always waiting for the steady-state condition before taking the next step.

During the tilt-table tests and before and after the exercise tests blood pressure was determined in the conventional manner at the brachial artery. A great deal of effort was expended in attempting to measure blood pressure during water immersion, but the results were almost totally unsatisfactory, it being impossible to obtain the necessary sensitivity in the pulse-sensing microphone in the presence of the high pressures associated with immersion.

Periodically during the immersion periods recordings were made of the vector impedance cardiogram (VIC). This is a newly developed technique for detecting the volume history of the heart during a single beat by means of two pairs of electrodes whose axes lie at right angles. The impedance changes as seen by the electrodes are converted into electrical signals by means of matched impedance transducers utilizing high-response load-sensitive 80 kilocycle oscillators. One pair is placed on the mid-axillary line, right and left at the level of the 6th intercostal space and the other pair are placed so their axis passes through the apex of the heart--i.e., below the left nipple on the front and just to the right of the spine on the back at the same level. The latter pair of electrodes feeds the Y axis of an oscilloscope and the axillary pair is connected to the X axis. When the breath is held, (to eliminate the very large slow changes in impedance associated with the respiratory movements), each beat of the heart draws a complex loop on the face of the cathode ray tube, which is interpretable by a cardiologist in terms of the hydraulic and mechanical events occurring in the heart. A polaroid camera was used to photograph the loop while it was held on the face of the storage oscilloscope.

In the control experiment, the electrodes for the VIC were held in place by means of double-faced adhesive rings. For the suited experiment these electrodes were permanently imbedded in the under-garment, and held against the skin by the natural elasticity of the foam neoprene of which this under-suit was made.

The peripheral pulse was recorded by an impedance transducer whose electrodes were placed above and below the elbow over the brachial artery. In addition to the recording of the shape of the volume pulse, this arrangement permitted the determination of the interval between the R wave of the EKG and the arrival of the volume pulse at the arm. The sweep rate of the scope or the paper speed of the oscillograph were maximized when this estimate of pulse-wave velocity was to be recorded. The experimental conditions, particularly the externally applied pressures coupled with the long duration of the experimental day precluded the use of a heart microphone which is a more common technique for pulse wave interval measurement. The block diagram for all the physiological measurements is shown in Figure 4.

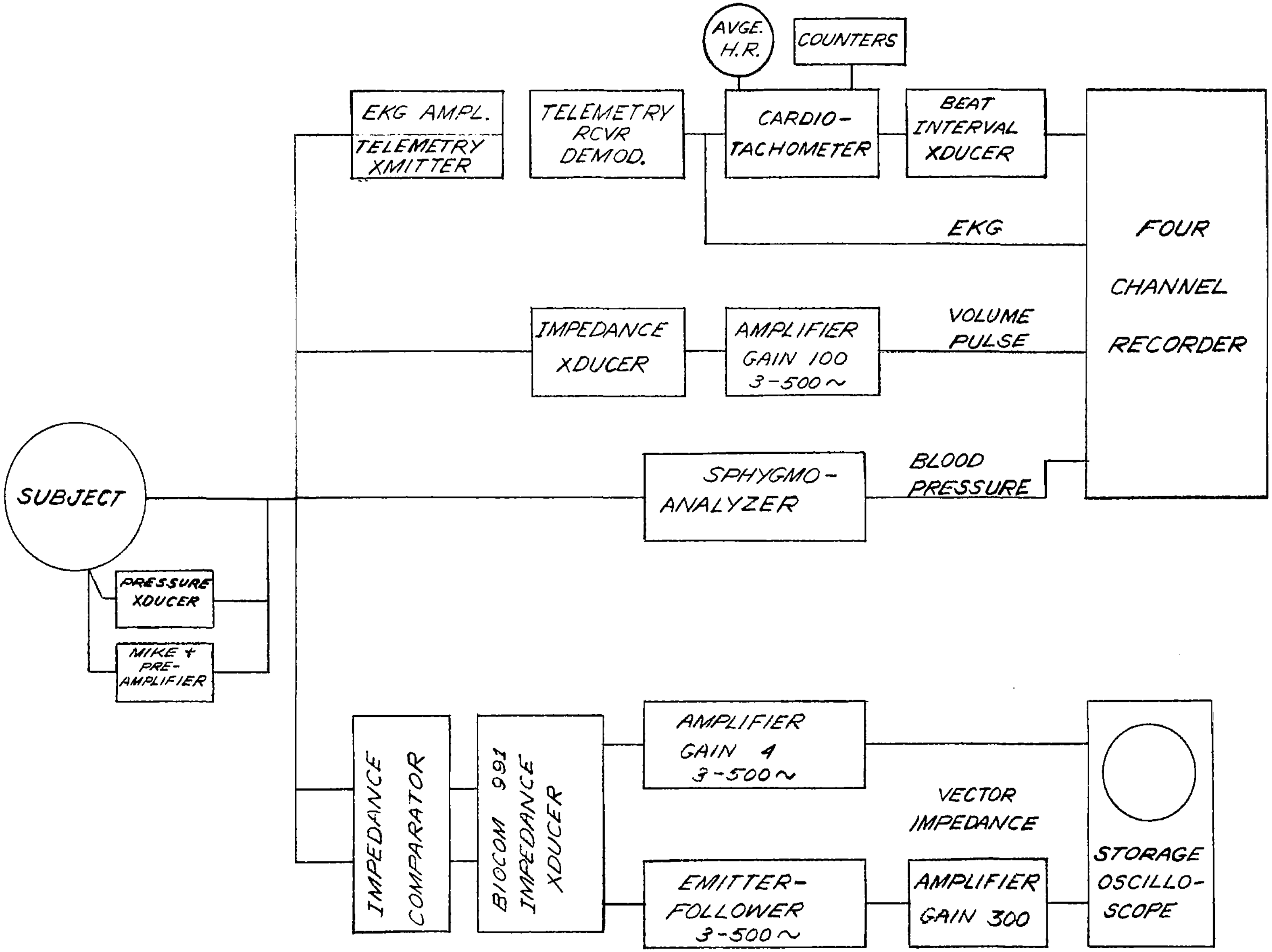


Figure 4: PHYSIOLOGICAL INSTRUMENTATION, CVCS EVALUATION TESTS

SUBJECT CHARACTERISTICS

The subject was a man of 26 years of age whose anthropometric dimensions fall relatively close to the 50th percentile for the 1950 U.S. Air Force population. He is a college graduate with a degree in general science, and was given a course in the theory and practice of SCUBA diving which qualifies him as a nationally accredited instructor in this sport. He weighed 160 lbs and was 71 inches tall.

During the design and fabrication of the suit this man served as a senior technician and participated in some of the actual construction phases of the suit and the experimental apparatus. In addition, he was encouraged to develop and maintain a state of physical fitness, and was given periodic tests on the treadmill to confirm the normalcy of his response to exercise. To imitate part of the physiological indoctrination which aviators and astronauts receive during their training experience, the subject was instructed in the techniques of positive pressure breathing, utilizing a full-face partial pressure helmet of British design, which was used without chest counter-pressure. He experienced several sessions of instruction and practice at breathing pressure levels of 20 to 30 mm Hg; the last of these was exactly one month before the start of the control experiment.

EXPERIMENTAL GARMENTS

Control test.--As a result of our great concern for the preservation of good skin hygiene, considerable pains were taken to ensure waterproofness of the outer suit worn by the subject. The electrode leads were sewn into a net shirt ("Brynje vest") which was worn over a conventional long sleeve, pullover type, "winter underwear" shirt. Ankle-length underwear pants and heavy socks completed the innermost layer. Over this was worn a form-fitting two-piece suit made of vinyl plastic, to the torso portion of which was attached the lower half of the helmet neck ring. The sleeves were sealed to gloves, and the pants legs had attached feet; jacket and trousers were taped together at the waist and sealed with liquid vinyl cement each day. Oversize canvas tennis shoes were worn to protect the vinyl feet of the outer suit.

The helmet is of the bubble type, with a spherical-shape transparent face plate permitting a wide angle of view in all directions except down. Breathing air is admitted through a fitting at the rear of the helmet, and is directed to the top of the face plate by a wide, flat duct running over the crown of the helmet. The incoming air flows over the face plate from a series of exit holes at the end of the supply duct.

Directly below the face plate and opposite the mouth when facing forward, is a second perforated duct which leads the exhaled air to the pressure-compensated exhale valve located on the side of the helmet. Sensing and pressure lines run from this exhale valve to the pressure-demand breathing regulator to provide a servo action to assist in opening the valve under any pressure differential conditions and in holding it open during the exhalation.

The two halves of the neck ring, one attached to the helmet and the other to the neck-piece of the undersuit, are held together by 2 heavy duty latches and sealed by means of a neoprene O-ring. Hold-down webbing straps are attached to the ring fore and aft, and pass through the crotch of the suit. Figure 5 shows various underwater views of the subject wearing this suit.

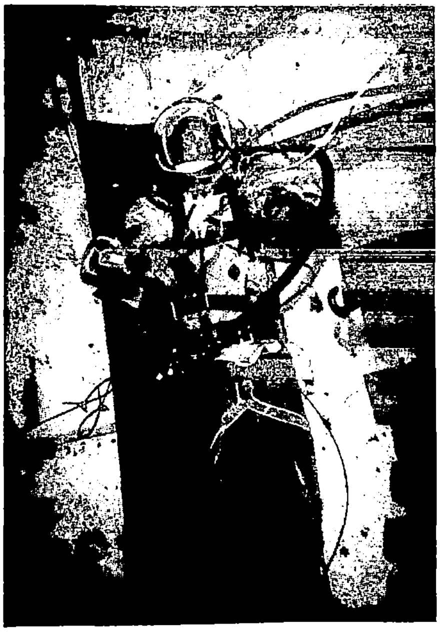
CVCS test. --The undergarment for the suited test immersions was specially constructed from the neoprene foam typically used in the "wet suits" used by SCUBA divers. It is form-fitting to be wrinkle-free, of two piece construction, with attached gloves and feet. The upper section incorporates a cloth-reinforced neck piece to which the helmet neck ring is attached, and a conical shaped high turtle-neck neck seal made of thin closed-cell foam neoprene.

Electrodes for the vector impedance cardiogram and the arm volume pulse are cemented into recesses in the inner surface of the 3/16 inch foam, and a pair of adhesive-coated EKG electrodes are permanently sealed into the material by their lead wires, with a free length extending from the inner surface to facilitate attachment of the electrodes to the skin. A pocket is cut into one arm to permit insertion from the outside of the blood-pressure microphone pick-up. The suit is high waisted for easy access to the electrodes, which are all in the upper section. See Figure 6 and the photographs in Figure 2.

After top and bottom of the foam suit have been donned (with the aid of liberal application of talcum powder) and all electrodes have been cleaned and/or attached, the two halves are sealed together by the use of the neoprene cement normally used for patching wet suits.

The CVCS itself consists of 6 separate segments, viz: arms, legs, shorts, and torso. Each segment includes a series of vinyl bladders, lightly tacked together and overlapping, and an outer restraint layer constructed of non-stretch fabric, containing adjustment lacing, shaping zippers, and attachment zippers for joining adjacent segments. Each of the water bladders or tori of the torso segment contains an internal air bladder, for the purpose of accommodating chest expansion during respiration.

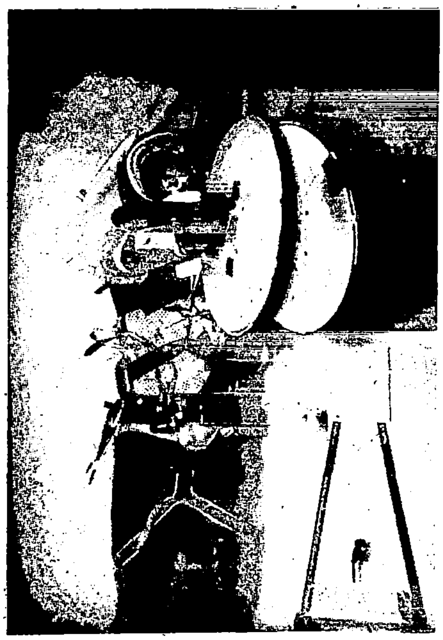
A photograph of the vinyl bladders is shown in Figure 8, while Figures 6 and 7 illustrate the construction details of the various parts of the CVCS. Figure 9 is a front and back view of the subject wearing the CVCS. The arm sections were removed to reveal the undergarment. These pictures were taken several days prior to the start of the CVCS experiment.



Resting on transport litter.

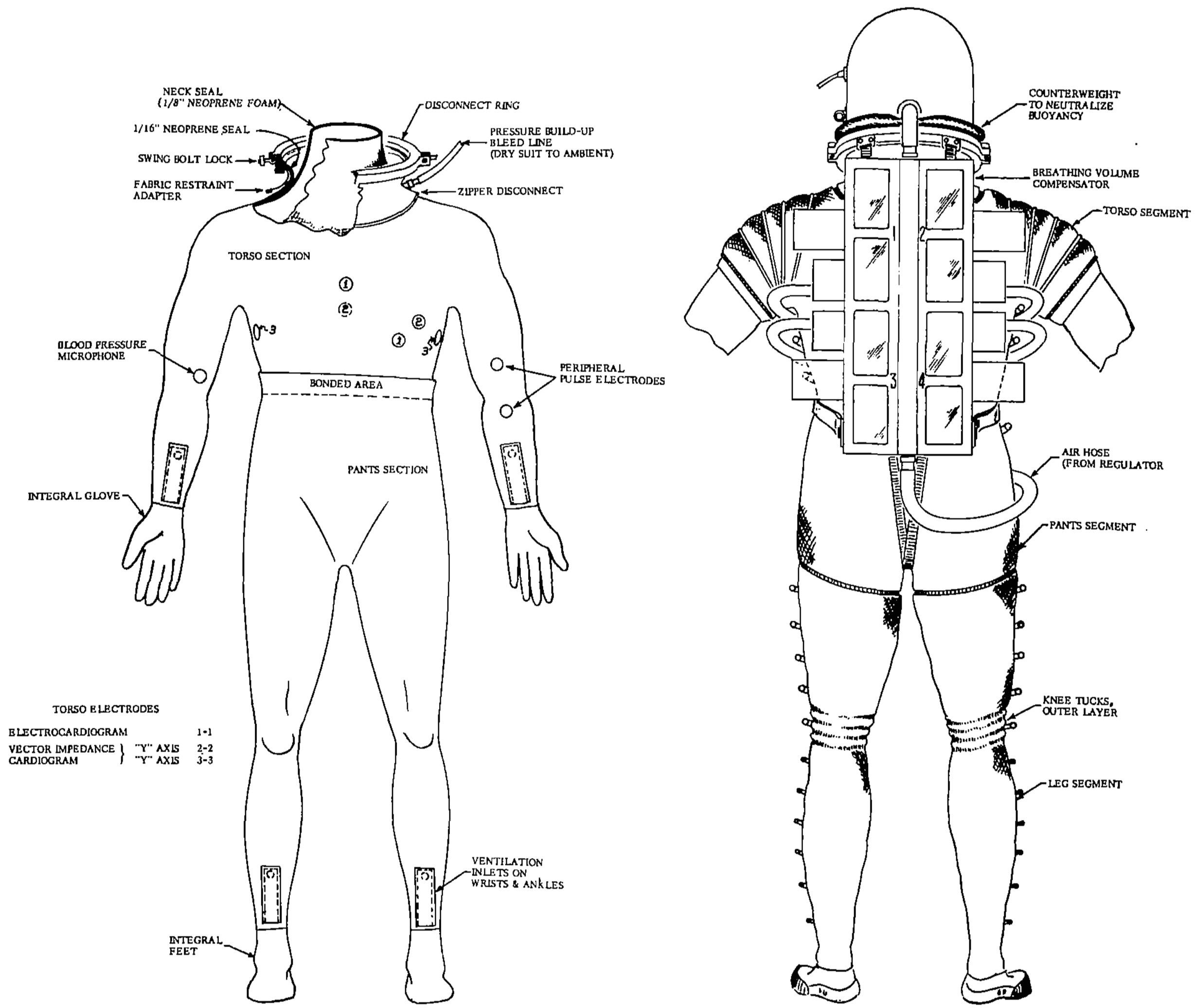
Jumping in place.

Reading paperback book.



Hydraulic resistance arm exercise.

Figure 5: VARIOUS ACTIVITIES AT THE BOTTOM DURING CONTROL EXPERIMENT



Dry Suit

Complete Suit and Accessories

Figure 6: CONSTRUCTION DETAILS OF THE CARDIOVASCULAR CONDITIONING SUIT (Part I)

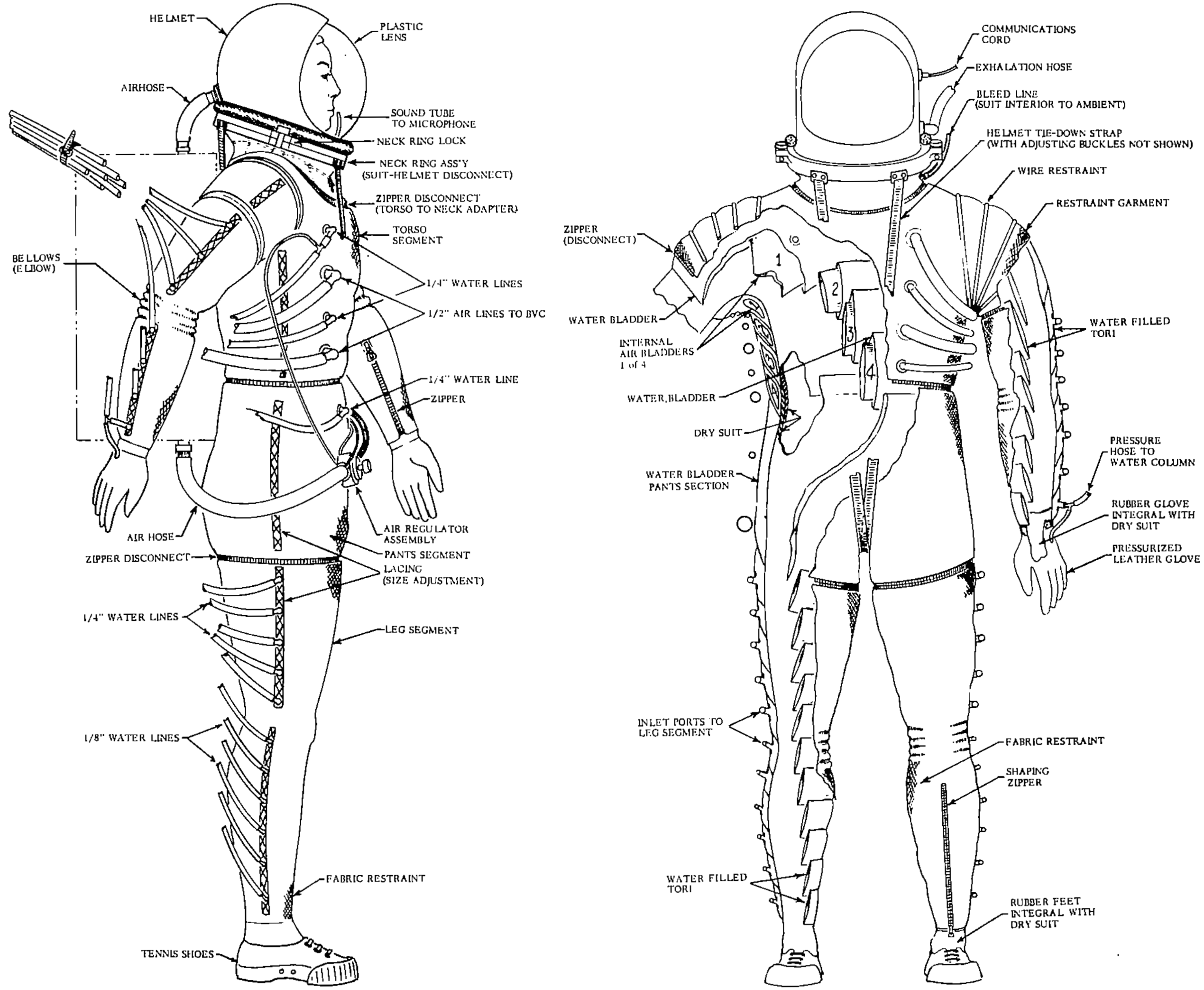


Figure 7: CONSTRUCTION DETAILS OF THE CARDIOVASCULAR CONDITIONING SUIT (Part II)

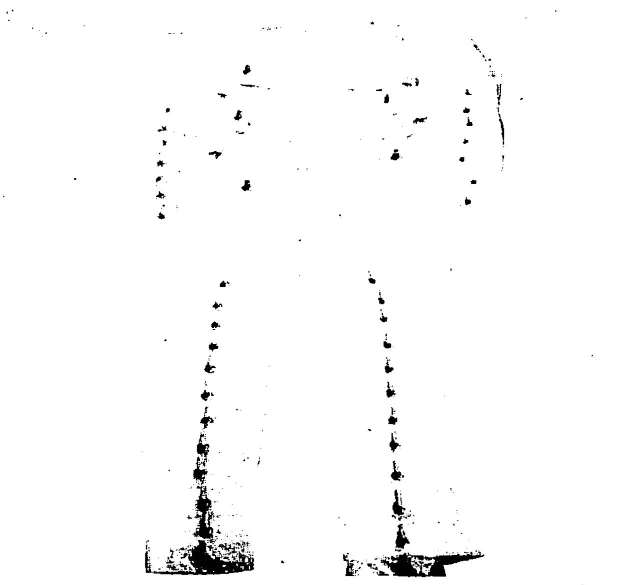


Figure 8: TOROIDAL BLADDER GARMENT; The Pressure Component of the CVCS

Figure 9: FRONT AND BACK VIEW OF THE CVCS, WITH HELMET AND FOREARM SECTIONS REMOVED TO SHOW THE NECK SEAL AND FOAM DRY SUIT

These pictures were taken 2 days before the first immersion day of the CVCS experiment, during a systems check.

PRESSURIZATION SYSTEM

The water bladders or tori of the CVCS are pressurized from a set of water reservoirs mounted on a movable rack (Figure 10). One reservoir is provided for each of the torso bladders and one for each pair of corresponding arm and leg tori. The height of each reservoir above the surface of the water in the 16-foot tank determines the differential pressure (pressure above ambient) applied by each torus supplied by that reservoir. The connecting flexible tubes are 32 feet long; the differential pressure remains the same, independent of the location or posture of the subject in the tank, since the water filled tubes exactly compensate, ensuring that the internal pressure in each torus changes by precisely the same amount as the external ambient pressure exerted by the surrounding water, when the man changes position.

Referring to Figure 10, one end of the reservoir rack (E) is fixed and acts as a pivot when the opposite end is raised by the lifting cable (A). This produces a height gradient in the reservoirs along the rack and thus a pressure gradient in the suit tori. The rack has 6 positions, 5 above the horizontal. In the top position (#6) the reservoir F_1, connected to the uppermost torso torus, is 51 inches higher in elevation than F_2 which is connected to the lowest ankle torus; similarly, each intermediate reservoir applies a pressure equal to the erect height above the foot of the anatomical segment enclosed by its torus or tori. It follows that the lower positions of the rack produce pressures in the tori of the suit equal (in inches of water head) to the height above the ground of the respective body segments when the body is tilted at some angle less than 90°. These pressures are shown in Figure 11.

When the lungs are pressurized by the breathing system to the same differential pressure as exists in the uppermost torus (height of F_1 above the water surface), a transmural pressure gradient is established throughout the vascular system which tends to distend the peripheral vessels. In position 6 of the rack, this gradient imitates closely the one which exists normally in an erect man, standing in air at 1G, who is 71 inches tall.

Since it was originally thought that the subject might not be able to tolerate long periods of full pressurization, a motorized winch (C) and logic control circuit was provided to permit rapid changes in rack position. The position sensing elements are six microswitches (B) located on the central mast and actuated by a one-half inch diameter metal teardrop clamped to the lifting cable. Switching the control box (D) located on the access platform (G) to the desired number quickly brings the rack to the correct new position where it is dynamically braked to a stop.

Provision is included in the rack design for raising the entire assembly parallel to the water by inflating an air bladder (H) until the whole assembly is buoyant. This feature was intended to permit the super-position of a gradient on a generalized positive pressure base. In Figure 10 the rack assembly is shown at its uppermost vertical height (3 feet above the water) to separate the elements and thus clarify the drawing even though no occasion arose during the experiment to require the use of this feature. The normal position had the load support collar (E) resting against the slide bearing secured to the access platform. Figure 12 shows two views of the rack and subject.

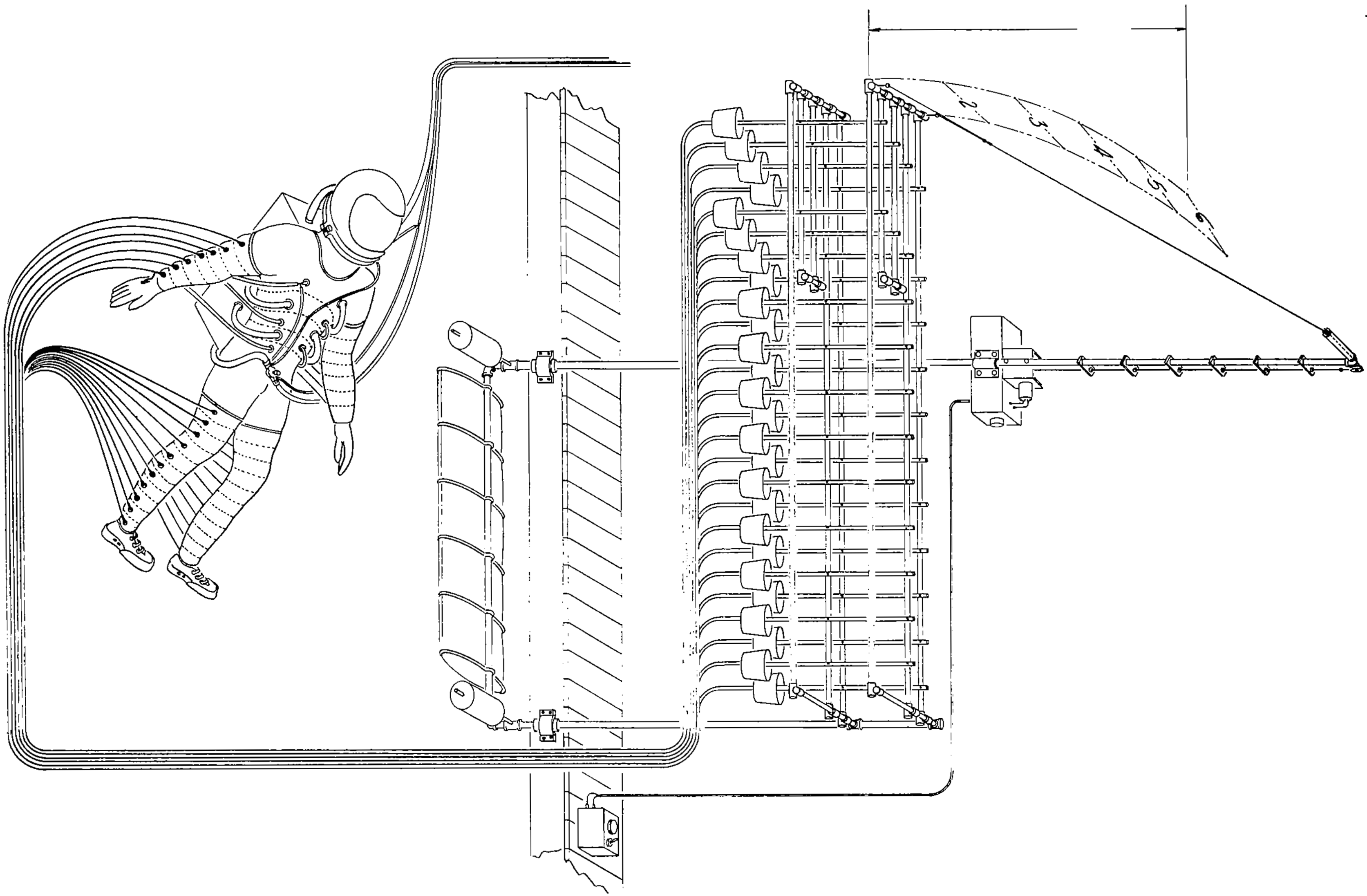


Figure 10: RESERVOIR SYSTEM FOR PRESSURIZATION OF THE CVCS

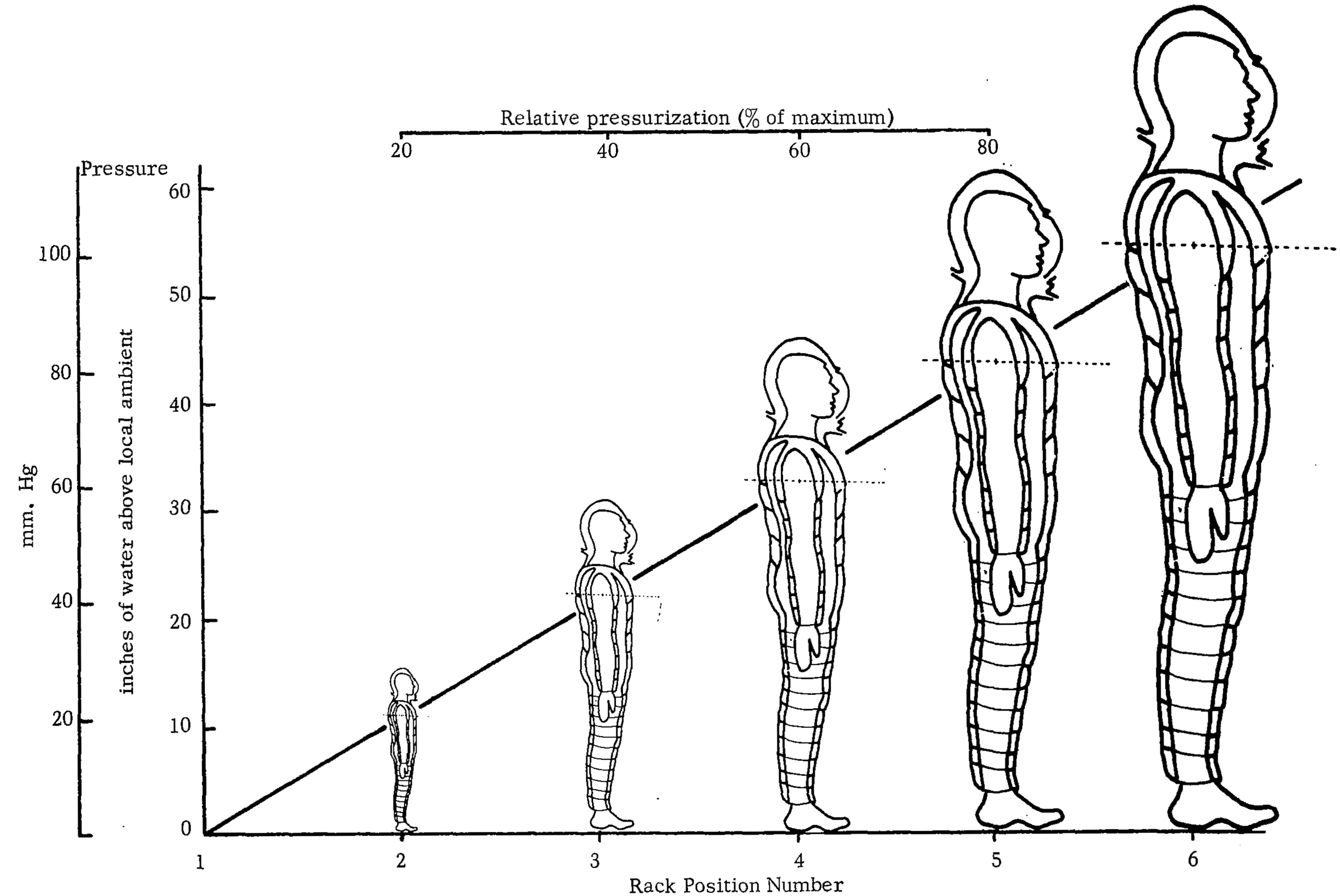
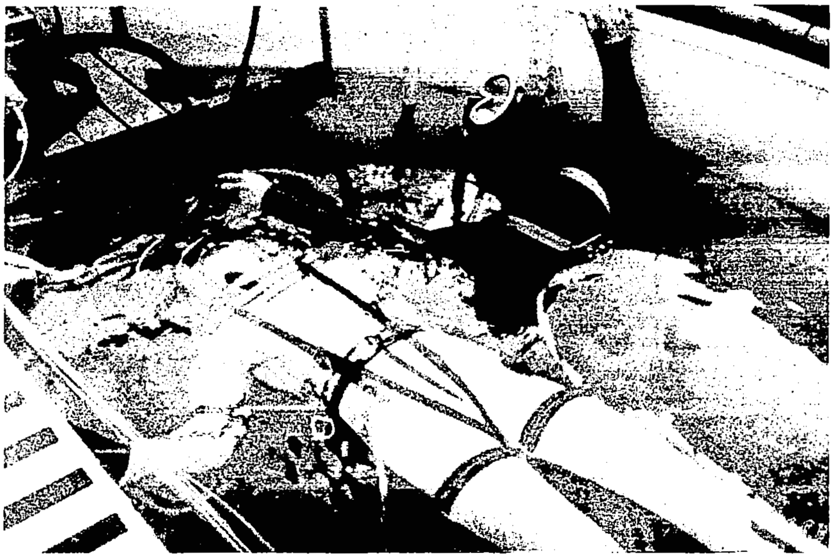
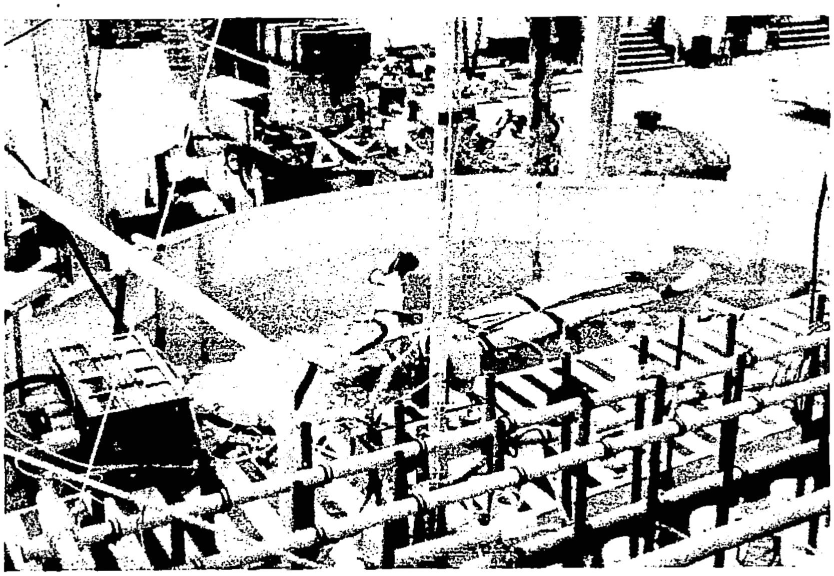


Figure 11: PRESSURE DIFFERENTIAL APPLIED TO EACH COMPARTMENT OF THE CVCS
at various positions of the reservoir rack



Subject relaxing, CVCS fully pressurized.
Safety diver checking hoses.



Partial view of reservoir, rack in #1 position;
subject and breathing volume compensator in background.

Figure 12: PHOTOGRAPHIC VIEWS OF THE PRESSURIZED SUBJECT AND RESERVOIR RACK

BREATHING VOLUME COMPENSATOR

To ensure individual and separate compensation of each torso air bladder for the expansion and contraction of the chest during breathing, as required by the sponsor's specification, a breathing volume compensator was constructed. The purpose of this device was to enable the volume of each air bladder in the torso section to expand and contract with every breath without any significant alteration in pressure, regardless of the orientation of the body in the water. The total pressure in each torus is the vertical distance of the water column from that body area to the corresponding reservoir at its elevated position above the surface of the tank (see Figure 9). When the body is vertical and the system is set for maximum pressurization (position # 6, Figure 10) these heights are all equal, whereas in the horizontal posture there is a pressure difference of 16 inches of water between the uppermost chest torus and the lowest one containing an air bladder. Because of the varying differences in pressure between compartments as body position in the water changed it was necessary to design and construct a system of self-adjusting bellows to automatically balance these differences. Figure 13 is a combination schematic-block diagram illustrating how one of the four compartments of the compensator functions. Basically, the air cylinder applies whatever additional force is required to keep the force differential across the bellows at zero. This maintains a neutral location of the bellows such that it can move in and out with little or no resistance, within the limit switches, as the subject breathes. A major change in either the bladder or breathing pressure will move the bellows against one of the limit switches causing an appropriate change in the air cylinder pressure to bring it back to the neutral position. Careful selection of the control circuit time constants prevents oscillation. Figure 14 shows an exploded view photograph of this unit and also how worn by the subject when submerged during the CVCS experiment. At times the breathing volume compensator required servicing. With the subject vertical in the water the four air bladders could be interconnected, their pressures being equal, and joined by a plennum to the pressure-demand regulator and the helmet to achieve the necessary volume compensation.

EXPERIMENTAL RESULTS

General physical condition. --Throughout both experiments the subject's general health as reported by the team physician, remained good. He did develop a minor upper respiratory infection on the 6th immersion day of the control experiment which was cleared up by the 10th day. Blood pressures taken daily by the doctor were in the range of 110/60 to 130/80 with no apparent trends in either experiment.

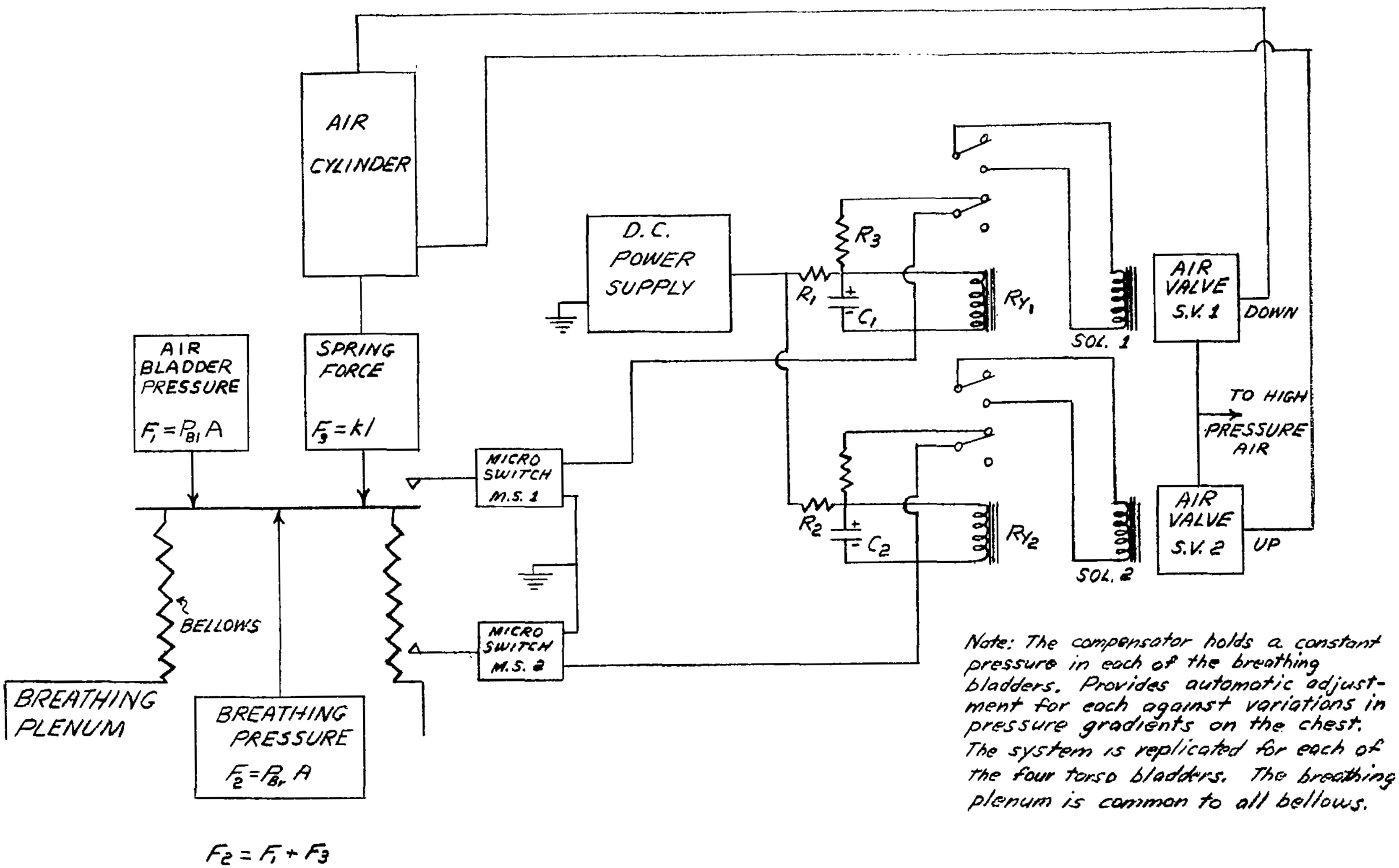
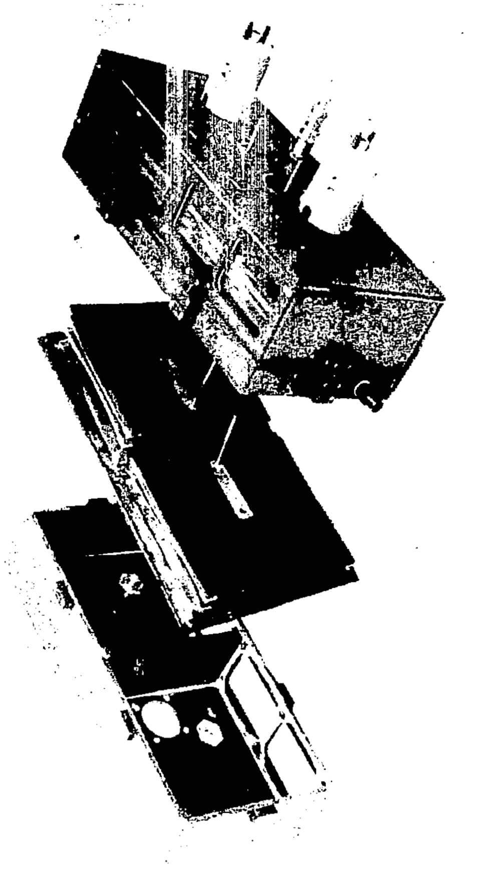
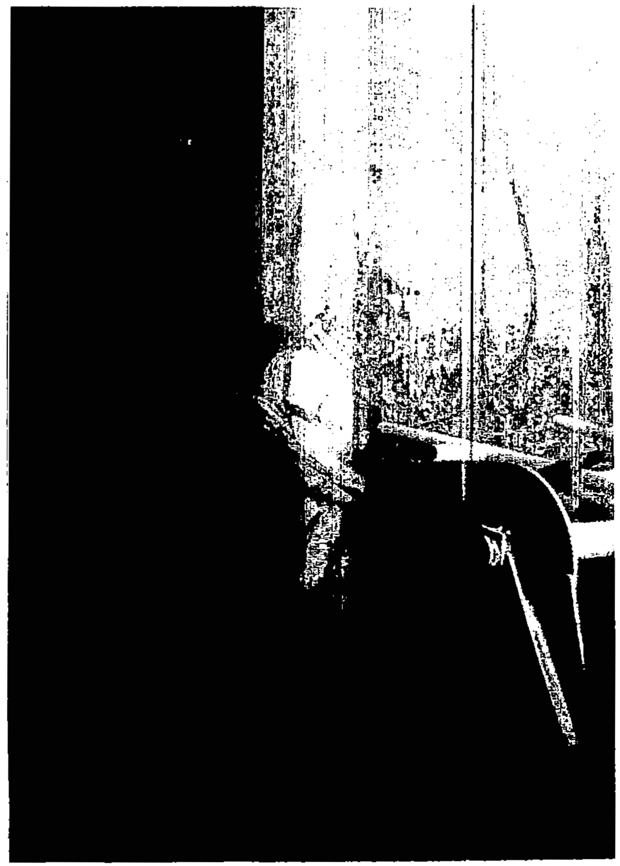


Figure 13: SCHEMATIC-BLOCK DIAGRAM; SELF-ADJUSTING BREATHING VOLUME COMPENSATOR



Breathing volume compensator exploded view; lower half disassembled from central plennum to show two of four compartments and bellows.



Subject wearing breathing volume compensator while pressurized at bottom of tank.

Figure 14: PHOTOGRAPHIC VIEWS, BREATHING VOLUME COMPENSATOR

Orthostatic tolerance changes.--In the control experiment, there was a drastic change in the response to tilt. From a normal pattern of adjustment, before the two-week exposure to a continuously hypodynamic environment, the picture during tilt at the end of the period became one of severe deterioration in the compensatory mechanisms with both blood pressure and heart rate falling rapidly and the development of pre-syncopal sensations, forcing termination of the tilt at the 11th minute. In contrast the first tilt test following the suited exposure was uneventful throughout the prescribed 20 minutes at 70°.

Figures 15 and 16 present the heart rate and blood pressure data recorded before, during and after tilt-tests performed before and after the two hypodynamic exposures.

In the case of the CVCS experiment, the differences in heart rate response between the two pre-immersion tilts and the one done at the end of the two week treatment with the pressurized suit are probably not significant, although the average heart rate was lowest (except for one reading) throughout the post-exposure tilt. Comparison between the pre-immersion and post-exposure tilt tests for the control experiment is complicated by the change in protocol (Figures 15c and 16). However, although the 15 minutes at 70° in the pre-immersion tilt were preceeded by 23 minutes at 45°, the initial heart rate was about the same as that measured before the 45° tilt; the rate increased for the first three minutes at 70° and then stabilized around a mean of about 98 beats/min. In contrast, in the post-exposure tilt the heart rate climbed more or less steadily after the first minute to a peak of 102 at 8 minutes. Thereafter it fell, moderately for the next two minutes and then abruptly in the last minute to a low of 61.5, when the tilt was terminated due to pre-syncopal symptoms and signs.

The pre-immersion and post-exposure blood pressure response to tilt for the control experiment are shown in Figures 15 and 16. The pre-immersion response is one of apparent compensation whereas in the post-exposure tilt the mean blood pressure begins to decline rapidly at about the 6th minute; by the 11th minute diastolic had dropped to 46 mm. Hg whereupon the attending doctor ordered the tilt terminated. In the suited experiment the same comparison (Figure 15) shows little difference in response between pre-immersion and post-exposure tilt as compared to the pre-immersion test with a somewhat smaller decrease in pulse pressure. Except for this the before and after curves are strikingly similar. Figures 15 c and d comparing heart rates and blood pressure during tilt at the end of both the control and suited exposures, show that utilization of the suit during immersion appears to have eliminated the deterioration of the response to tilt which two weeks of a continuously horizontal posture interspersed with daily immersion otherwise causes.

Tilt tests were also performed on each of the first four recovery days following both the control and suited hypodynamic exposures. The data from these tests are presented in Table 2. Following the control exposure heart rates during tilt were elevated until the third recovery day; blood pressures were more normal although the diastolic pressures were somewhat elevated on the 1st, 3rd and 4th recovery days. On the recovery days after the suited exposure heart rates are comparable to the pre-exposure levels but the systolic pressures are somewhat elevated.

Data for the early qualifying tilt tests are included in Table 3.

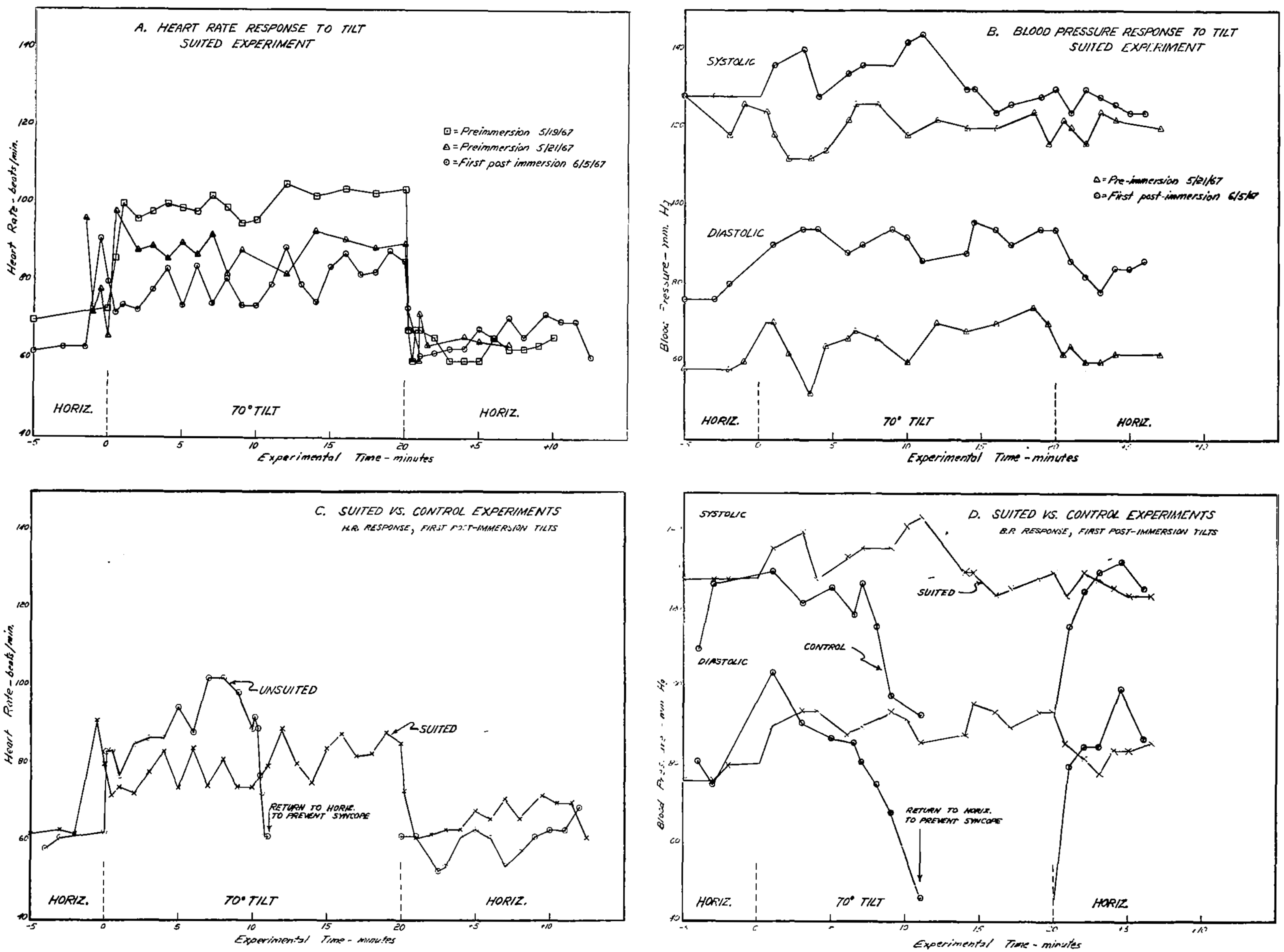


Figure 15: CARDIOVASCULAR RESPONSE TO A 70° TILT, BEFORE AND AFTER TWO-WEEK EXPOSURES TO BED-REST AND IMMERSION, WITH AND WITHOUT THE CVCS

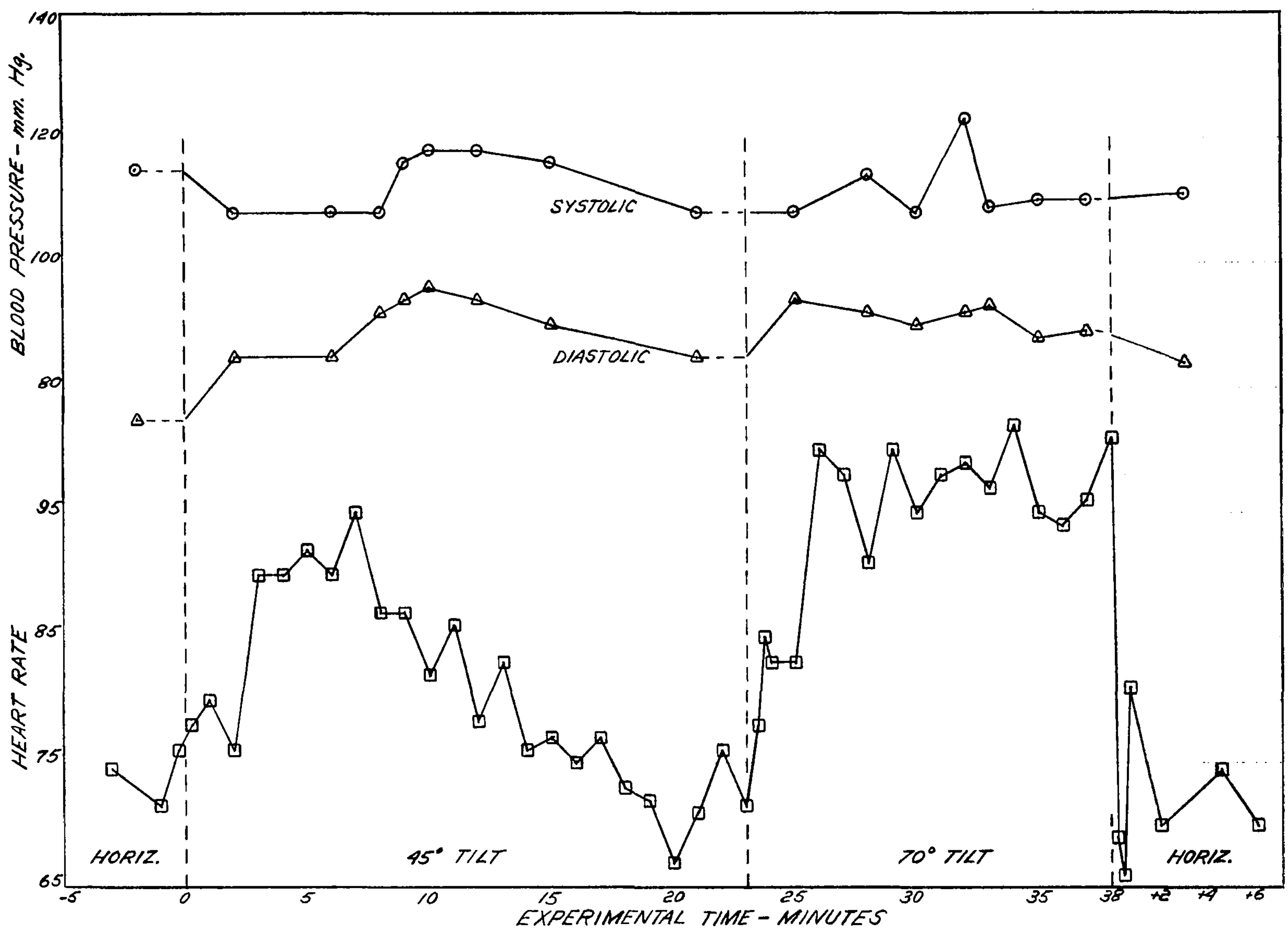


Figure 16: CARDIOVASCULAR RESPONSE TO TILT, BEFORE TWO-WEEK EXPOSURE TO BED-REST AND IMMERSION, CONTROL EXPERIMENT

TABLE 2

CARDIOVASCULAR RESPONSE TO TILT,
Recovery Days 1-4, control and CVCS experiments

Time (minutes)		CONTROL EXPERIMENT								SUITED EXPERIMENT							
		R_1		R_2		R_3		R_4		R_1		R_2		R_3		R_4	
		H.R.	B.P.	H.R.	B.P.	H.R.	B.P.	H.R.	B.P.	H.R.	B.P.	H.R.	B.P.	H.R.	B.P.	H.R.	B.P.
Horizontal	-2	74	129/77	90	116/72		108/77	74		76	126/62	78	132/68	84		80	126/62
	-1	72		90	116/66	75	114/76	70		77	138/66	70	126/68	83	134/54	68	
	-0.15	75		90		73			110/92								
70° Tilt	0																
	0.15	91		87				81		82	128/68	92		92	130/65	82	144/76
	1	94		110	111/70	88	118/90	78		95	130/68	94	124/74	99		84	128/72
	2	104	128/76	111	108/66	95	108/88	85		82	130/68	99	118/68	104	130/70	86	124/68
	3	102		112	96/70	96		91	108/90	102	130/68	102	118/64	111	120/70	89	128/70
	4	108		111	100/70	104	110/88	92		98		100	124/74	106	124/74	92	126/72
	5	106	122/75	112	106/70	101		91		98	125/67	97		108	126/75	92	
	6	110	120/79	116	106/70	101	118/87	89		94	122/68	102	126/76	108	134/74	90	130/65
	7	103	113/79	117	106/70			89	112/90	106		94	124/66	106		90	
	8	115		118		102	107/90	90		98	130/68	93		109	132/75	96	132/70
	9	112		120	96/70		114/90	89		104		97	116/70	109	118/78	91	
	10	116	122/81	120		102	115/88	89	114/88	98	124/66	100		105	122/76	91	128/72
	11	116	116/81	120	100/66			88		91		94		102		92	
	12	120		118		100		91		91	116/70	103	116/72	105	120/74	86	125/68
	13	116	118/85	116			112/90	89		99		100		104		93	
	14	112		118		96		92		94	122/72	106		107	122/76	93	124/72
	15	103		124	102/70		112/90	92		104	125/65	106		110		94	
	16			116		100.5	110/87	91		98		102	126/78	106		94	126/66
	17			127				92		94	120/62	106		110		92	
	18			128			108/92	91		102	126/68	108	103/76	111	112/76	93	128/66
	19.45			122			110/92	87	112/90	106	125/70	105	108/76	110	114/80	92	136/72
Horizontal	20			118	100/64												
	0.15	70		61.2	126/66	56		52									
	1	68		80	112/64	73	108/88	71			118/52	86	120/58	78	132/62	82	128/60
	2	73		80	112/70	73	114/75	69			125/56	75	118/66	75	130/66	75	132/60
	3	67	131/72	80	116/72		116/76	65				80	116/70	74	138/68	77	135/58
	4	70	125/74	83		72		67			130/60	78	122/70	73		70	
	5	69		83				70					128/70	73	130/64	73	128/60
	6	76		82		67	115/76	70			126/57	78	124/70	75		71	128/60
	7	74	131/77					92					128/76	77	132/66	75	
	8	67						90			124/62					74	
	9	68	118/80												128/70		
	10			80		91.8					126/58				132/68		

Table 3

HEART RATES DURING
QUALIFYING TILT TESTS, 11/10/66
(beats/minute)

Experimental Time	Test # 1 (10 minute tilt)	Test # 2 (15 minute tilt)
	HORIZONTAL, PRE-TILT	
-2	68	70
-1	70	65
	70° TILT	
0.10		84
0.20	84	78
0.30	84	72
0.40	78	84
0.50	84	
1	96	90
2	92	96
3	89	94
4	91	97
5	95	94
6	90	91
7	89	94
8	94	98
9	86	92
10	89	92
11		90
12		93
13		93
14		98
15		87
	HORIZONTAL, POST-TILT	
+0.20	86	87
+0.30	78	66
+0.40	60	60
+0.50	60	
+1	84	63
+2	58	57
+3	63	63

Note: These short tests were conducted to determine if the subject was prone to syncope. No blood pressure data were taken. The termination points were arbitrary; no subjective symptoms were reported.

Response to brief mild exercise--The task of climbing and descending two flights of stairs at a controlled moderate pace was found to be a sensitive indicator of cardiovascular compensation (or lack of it) during the period of recovery from the first two week control experiment. On recovery day two, following termination of the control bed-rest/immersion exposure (i.e., approximately 40 hours after the final removal from the tank), a pulse count of 75 beats in 30 seconds was recorded during the second half of the one minute required to complete two ascents and descents of the two flights.

Unfortunately, instantaneous heart rate was not being recorded during this first test, though each heart beat was accumulated on the electric counters of the tachometer-totalizer. It was obvious, however, that each beat-to-beat interval was progressively shorter from start to finish of the final 30 seconds. In Figure 17b the curve for this first test (R_2, control) which is based on 30-second actual counts, is extrapolated to indicate a probable final heart rate of 160 beats/minute at the end of the 30 seconds in which 150 beats/minute is the average rate. Figure 17b compares the heart rate response to the stair-climbing exercise on days R_2 and R_3 of the control experiment with that observed immediately post-exposure on day 15 of the CVCS experiment.

In the days preceeding the second 2 week exposure this same one minute test was performed on three separate occasions. The peak heart rates at the end of the work ranged from 132 to 144 per minute (based on 15 second pulse counts), suggesting that the physical fitness status of the subject might have deteriorated somewhat since the recovery from the control experiment.

The first post-exposure test following the CVCS experiment was done one hour and 15 minutes after removal from the water and immediately following the tilt table test. The subject had been on his feet only about 20 minutes in total; the peak heart rate, read from the instantaneous beat interval record, was 119 to 122 beats/minute. At 1 minute of standing recovery the rate was down to 98, and at 3 minutes reached a low of 77 beats/minute.

Table 4 presents the heart rate data for all the brief exercise tests. Figure 17a deals with the CVCS experiment and compares the initial post-immersion test performed on day 15 with the pre-immersion test and the one performed on day R_1. It should be noted that there was a lesser rise in the working heart rate immediately following the 2-week exposure than in the pre-immersion or R_1 tests.

Figure 17b compares the control experiment with the CVCS experiment in a necessarily indirect manner, viz. days R_2 and R_3 in the control versus the first post-exposure test on day 15 of the CVCS experiment. It will be seen that the latter compares favorably with control day R_3, while the response to work on control day R_2 was extreme compared with the post-CVCS test. To compare the two R_2 tests directly, one must use as the control data the interpolated heart rate at 30 seconds, 138 beats/min and the extrapolated final value at 1 minute of work, 160 beats/min. The comparable mid-point and final heart rates in the R_2 test of the CVCS experiment, (from Table 4) are 116 and 144 beats/min respectively. While the significance of these differences is uncertain, it is worth noting that the test on R_2 of the CVCS experiment was performed late in the day (7:15 pm) and followed an hour of calisthenics which left the subject extremely fatigued. The cardiac response to the various exercises which make up the workout is indicated in Table 5.

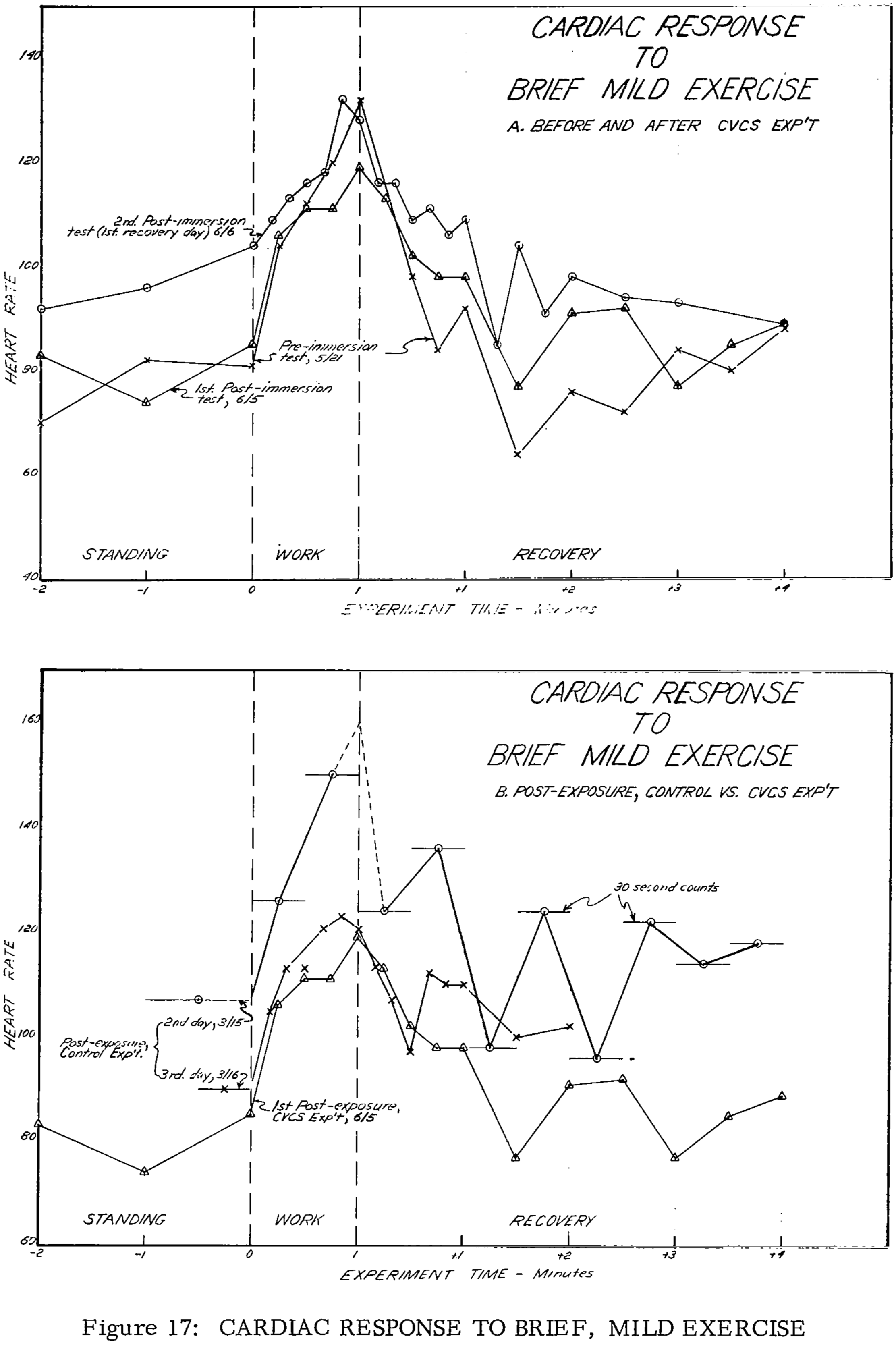


Figure 17: CARDIAC RESPONSE TO BRIEF, MILD EXERCISE

Table 4

BRIEF MILD EXERCISE HEART RATE DATA

Experimental Time (mins., secs.)	Control Experiment			CVCS Experiment					
				Pre-Exposure					Experiment Day
	R_2	R_3	R_4	5/19	5/19	5/21	15	R_1	R_2
-1	107	90	90	102	94	81	74	96	101
Start 0									
0:10		105	95	92	96	104	106	109	92
0:20		114	104					113	
0:30	126	114	102	124	124	112	111	116	116
0:40		120	106					119	
0:50		123	111	136	128	120	111	132	128
1:00	150	120	109	136	144	132	119	128	144
Recovery									
+0:10		114	104	112	120		113	116	112
0:20	124	107	99					116	
0:30		97	98	108	104	98	102	109	120
0:40	136	112	94					111	
0:50		110	92	100	104	84	98	106	108
1:00		110	98	104	104	92	98	109	116
1:30	98	100	77	100	90	64	77	104	104
2:00	124	102	72	94	94	76	91	98	100
2:30	96		77	94	92	72	92	94	84
3:00	122		74	96	106	84	77	106	100
3:30	114			98		80	85	95	98
4:00	118			108	94	88	89	98	110

TABLE 5

HEART RATES DURING WORK-OUT
2nd day of recovery, CVCS experiment, 6-7-67

ACTIVITY	TIME	FINAL HEART RATE Work	Rest
Jumping Jack, raising hands and knees with short hops, toe touch, squat, (30 sec. each)	2 min.	162	
Rest, supine	2 min.		106
25 push ups	1 min.	152	
Rest, supine	1-1/2 min.		111
31 sit ups	2 min.	152	
Rest, supine	3 min.		119
Side bend, neck rotation, splits (1 minute each)	3 min.	162	
Rest, supine	3 min.		116
Supine position, kick with stiff knees	1 min.	152	
Rest, supine	1 min.		116
Squats	1 min.	162	
Rest, supine	5 min.		111
Slow running	5 min.	185	
Rest, supine	5 min.		111
"Yoga" exercise, (stretching of hip, shoulder and back muscles)	9 min.	152	
Rest, supine	3 min.		119
Stair climbs (2 flights) and descends (5 times)	3 min.	185	

Work capacity tests.--The tests performed on the bicycle ergometer before and after the 2-week bed-rest/immersion exposures showed opposite changes in ultimate work capacity for the control and the CVCS experiment. In both cases, the heart rate in the post-exposure tests was lower at the beginning of exercise and higher at the exhaustion point than in the corresponding pre-exposure trial; however, the duration of work at the final and maximum load level of 250 watts was longer by 30 seconds, or 20%, after the exposure than before in the experiment where the CVCS was used. After the control experiment, by way of contrast, the subject reached his voluntary limit of exhaustion before completing the penultimate load step, stopping after 1 minute at 225 watts, whereas before the exposure he had completed 1.5 minutes at 225 plus one minute at 250 watts.

Thus there was a distinct drop in the indicated work capacity as a result of the control exposure to the hypodynamic environment, whereas the data show an equally distinct, though smaller increase in work capacity following the 2 week exposure utilizing the CVCS. This contrast is even more impressive in the light of the fact that the total amount of submerged activity was much greater in the control experiment than in the suited one. In the control experiment the subject was on the bottom of the tank most of the time, with considerable freedom of movement, and he carried sufficient weights to make him negatively buoyant by some 25 pounds (thus simulating lunar weight). By choice he did a good deal of moving about on the bottom as well as carrying out frequent exercise periods, during which he would jump up and down, use a child's "pogo stick", practice the flutter kick while holding himself horizontal by grasping the bottom of the tank's ladder, or exercise his arms by swinging giant "cymbals" through the water. (See photograph in Figure 4.) For the CVCS experiment, exercise was largely limited to occasional periods of kicking and arm bending, while the man floated at neutral buoyancy with the suit pressurized.

Figures 18a and b show the time course of the heart rate response to the graded steps of the ergometer tests used in the control and CVCS experiments. It should be noted that there is no actual elapsed time from the voluntary end point to the start of the recovery period; this method of presentation was used to preserve a common time base as an aid in comparing the data. Figure 19 presents the same heart rate data for both experiments in terms of the cumulative work accomplished.

In the post-exposure curve for the control experiment (Figure 18a) the heart rate at 125 watts load, 14 minutes after the start, starts to exceed the value recorded at the same point in the pre-immersion test. More significant, perhaps, is the fact that the steep rise begins at 8 minutes, during the 75 watt period, whereas in the pre-exposure test the comparable steepening of the curve does not begin until 15 minutes, during the 125 watt load period.

After the CVCS experiment (Figure 18b) the difference between post- and pre-exposure responses does not show up until the end of the 200 watt load period, at 6 minutes, and there is a much less distinct separation between the curves at their upper or exhaustion end. The final heart rates in the CVCS experiment differ by only 8 beats, whereas in the control experiments, the difference is 12.

In Figure 19, where data for both control and CVCS experiments are plotted together, a comparison can easily be made of the difference between pre- and post-exposure tests. The slope (change in heart rate per unit increase in expended energy)

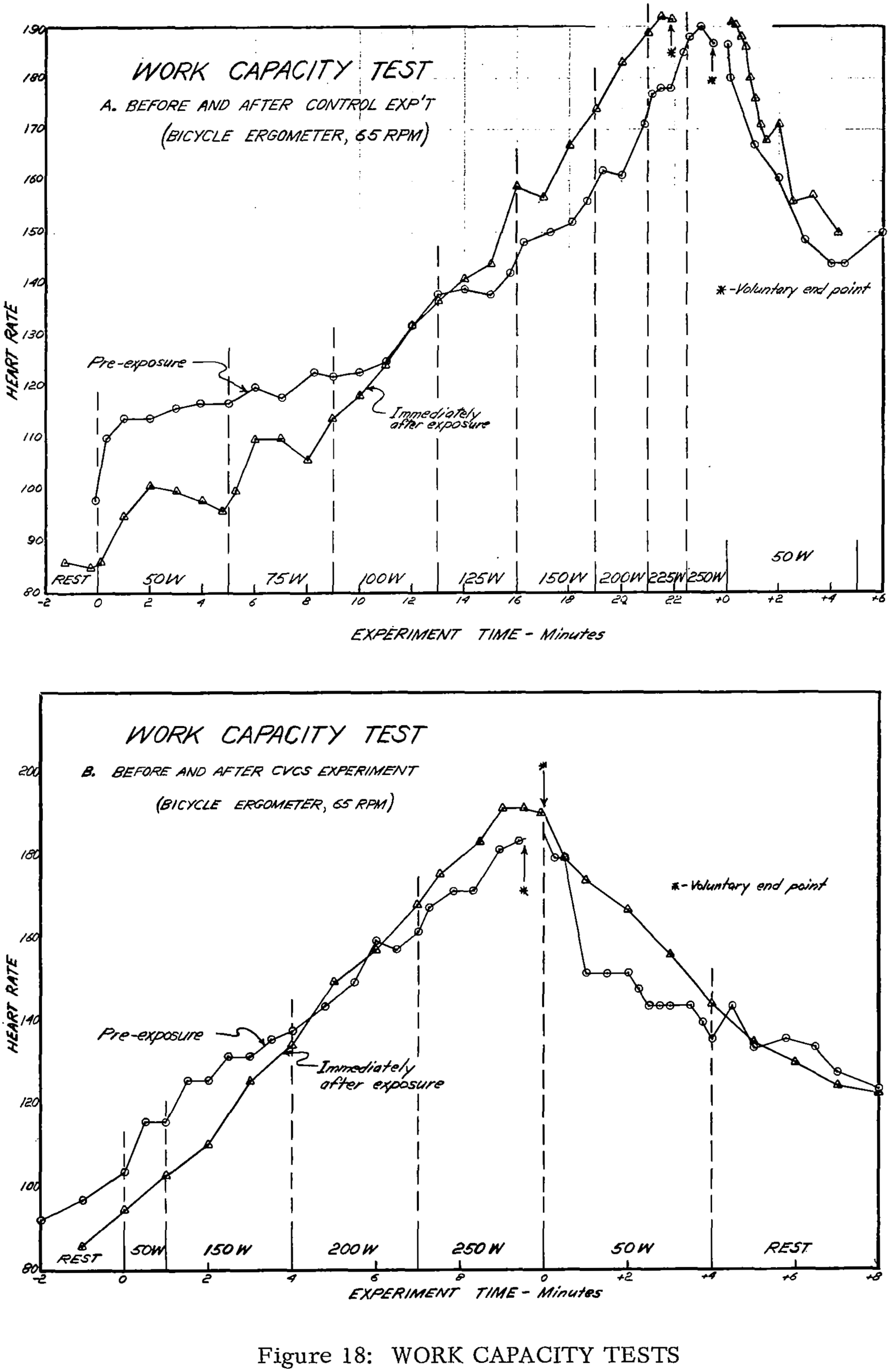


Figure 18: WORK CAPACITY TESTS

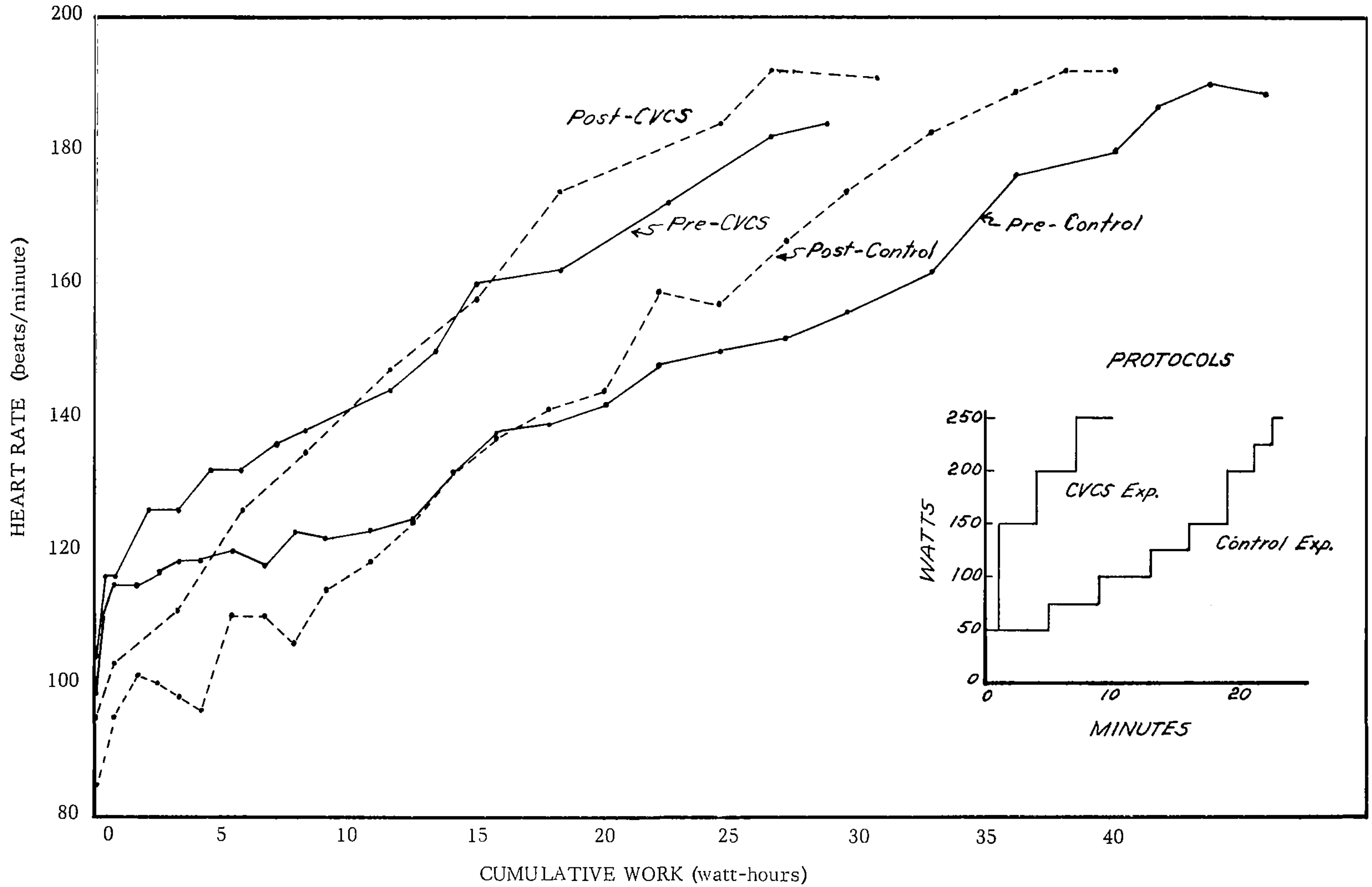


Figure 19: INTERCOMPARISON OF THE 4 ERGOMETER TESTS,
before and after the 2-week exposure
CVCS and Control experiments

of the post-exposure curve in the control experiment is 50% greater than the pre-exposure curve, while for the CVCS experiment the post-exposure slope is only 34.5% greater than the matching pre-exposure slope.

The progressive alterations in the EKG configuration during the ergometer test are compared between the two post-exposure ergometer tests in Figure 20. The general character of the changes seems to be quite similar, but there are some differences in detail which may or may not be significant. For example, the S-T segment seems to become more severely distorted early in the post-CVCS test than at the comparable state of the post-control test. Also, the inverted small T wave, elevated T-P segment and exaggerated P wave in the recovery phase of the post-CVCS test is distinctly different from the corresponding traces in the post-control test, in which the only deviation from "normal" is a possible slight S-T depression.

On the evening following removal from the tank on day 15 of the CVCS experiment, the subject continued to wear the EKG electrodes and telemetry transmitter which were used during the work capacity test on the ergometer. Periodically, at random, recordings were made of the EKG. Figure 21 presents samples from these recordings, identified as to the time of day and the general nature of the activity at that time. In general during this period the subject was moving quietly about his quarters and the general area, relaxing and enjoying the chance to be out of bed. He felt tired after the long and eventful day, climaxed by the severe exercise of the ergometer test. Note that the only "normal" trace on the evening of day 15 is the one taken in the supine position (which happens to be at twice the standard paper speed).

For comparison with these post-exposure electrocardiograms we have included in Figure 21 a number of sample traces from the next two days (R_1 and R_2) when the subject was engaged in ordinary kinds of activity in a generally vertical posture. Figure 21 shows that the EKG abnormalities seen at the end of the post-CVCS ergometer test were still present at bed-time that night, but had disappeared by the next day. However, there were still some definite suggestions of irregularity in the EKG during mild exercise, such as occasional disappearance of the P wave or diminution in height of the T, on days R_1 and R_2.

To aid in the interpretation of these EKG changes we have collected in Figure 22 some representative records taken a month before the control experiment and during the two exposures. These traces illustrate the fact that before and during hypodynamic exposure, the changes produced by exercise seldom persisted more than a few minutes after the end of the exercise. This picture contrasts with the rather substantial changes in pattern seen in the CVCS post-exposure period when any load was placed on the heart beyond that of the supine rest condition.

<u>Venous compliance changes</u>.--The basic measurements from which venous compliance is computed is change in arm girth as a function of occlusion pressure of the arm veins. Whitney has shown that the per cent change in volume of the limbs is double the per cent change in girth (ref. 7). Figure 23 presents data for the pre-immersion and post-exposure determinations in both control and CVCS experiments. It will be noted that the two pre-exposure curves show roughly 15 times the expansion at 30 as at 10 mm. Hg, while the expansion at 60 mm. Hg is only 1.5 times that at 30 mm. Hg. The most striking aspect of the graph is the complete and distinct separation of the control experiment post-exposure data (uppermost curve square symbols) from the other three sets of measurements. Even at 10 mm. Hg occlusion pressure

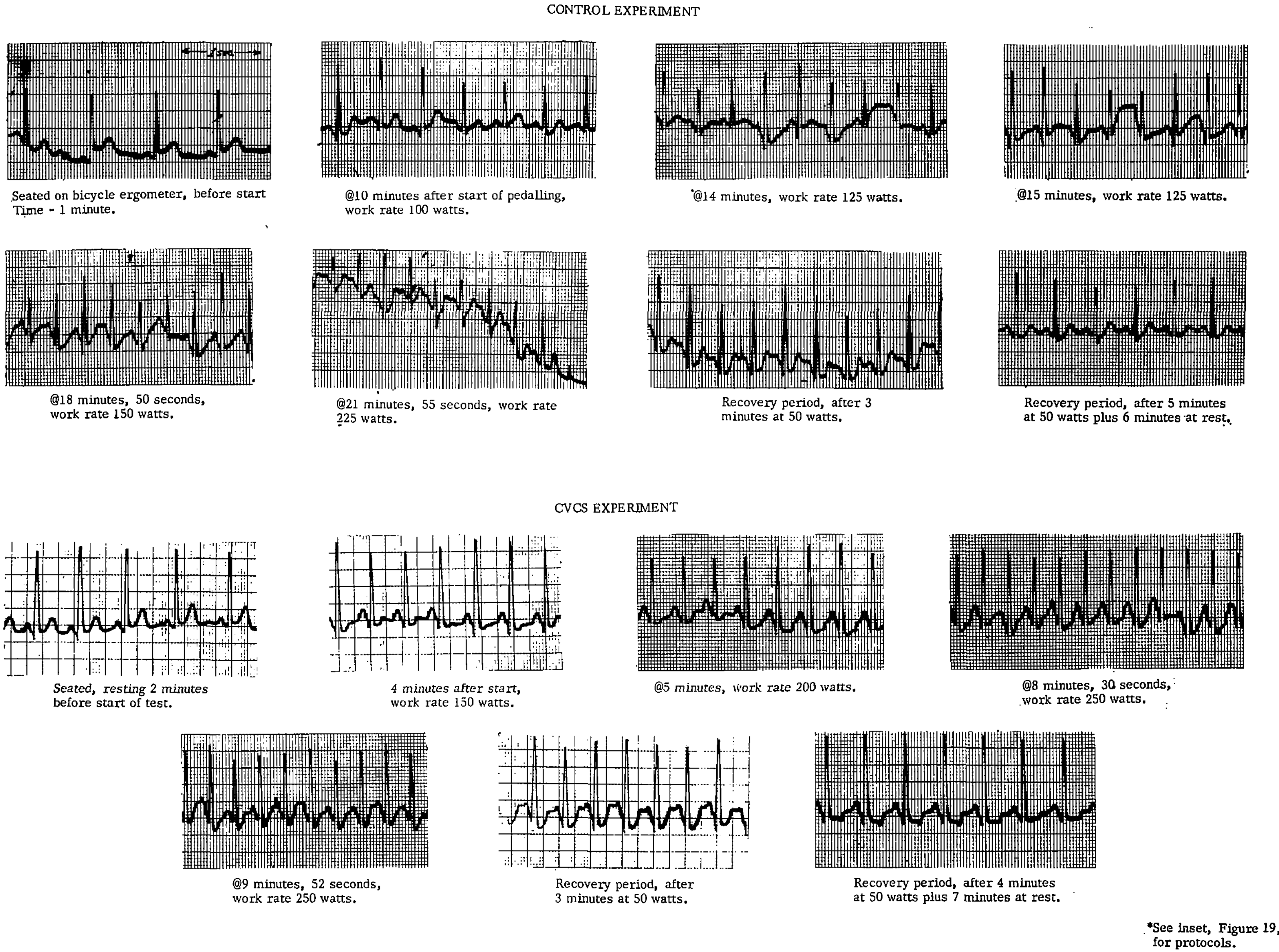
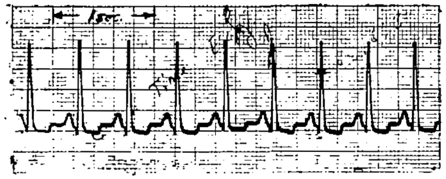
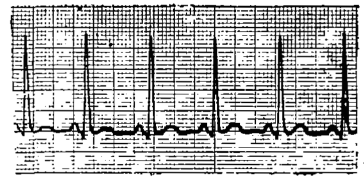


Figure 20: EKG COMPARISONS DURING AND AFTER THE FIRST POST-IMMERSION WORK CAPACITY TESTS
Control and CVCS Experiments

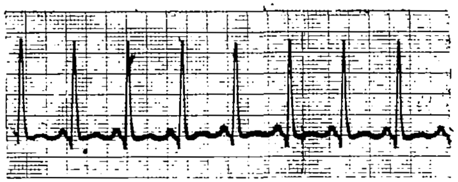


Day 15, 8:18 p.m. Seated, talking (9 minutes after stair climbing test). H.R. 125

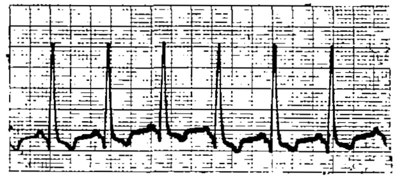
Day 15, 8:44 p.m. Supine, asked to relax completely for venous compliance determination (paper speed=50 mm/sec). H.R. 82



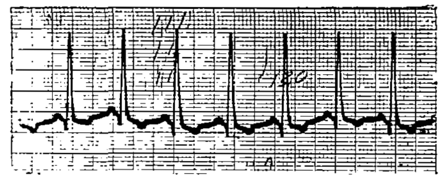
Day 15, 9:06 p.m. Sitting, watching television. H.R. 94



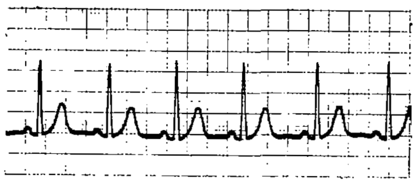
Day 15, 9:30 p.m. Sitting, eating dinner and watching television. H.R. 109



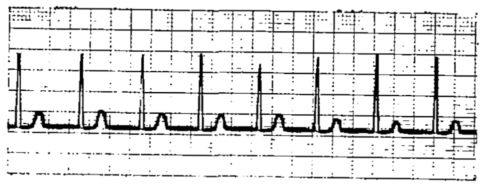
Day 15, 10:07 p.m. Sitting, watching television. H.R. 107



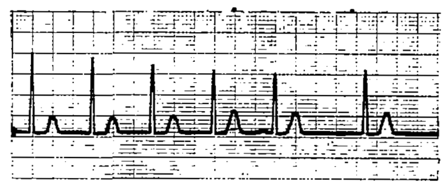
Day 15, 10:41 p.m. Sitting, watching television. H.R. 109



R_1, 10:16 a.m. Seated at rest. H.R. 88

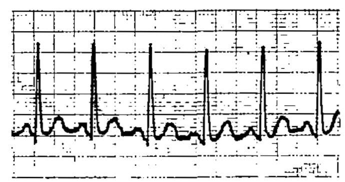


R_1, 11:43 a.m. Standing, reducing data. H.R. 102



R_1, 12:11 p.m. Sitting on bicycle ergometer having photograph taken. H.R. 100

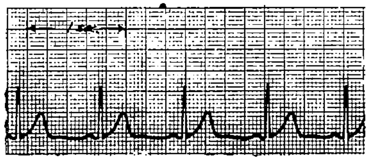
R_2, 2:22 p.m. Walking from instrument room to trailer during normal activity. H.R. 120



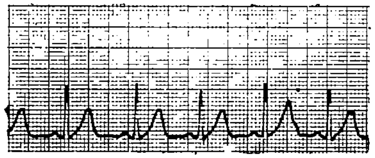
R_2, 5:56 p.m. Seated at desk reducing data. H.R. 107

Figure 21: EKG RECORDS TAKEN DURING THE FIRST EVENING AT 1G AND ON RECOVERY DAYS 1 AND 2 (CVCS EXPERIMENT)

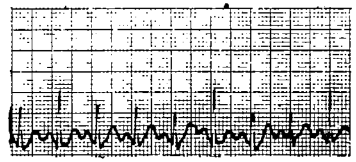
JANUARY 28; ONE MONTH BEFORE CONTROL EXPERIMENT.



2:47 p.m. Seated at rest. H.R. 70



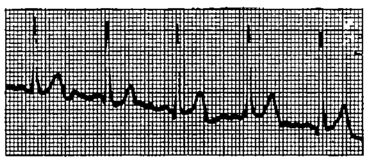
3:27 p.m. Strolling @ 2 mph on treadmill, level. H.R. 94



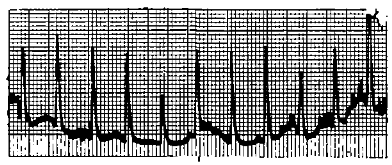
3:41 p.m. Intermittent climbing 20% grade @ 4 mph, 10 secs on-10 off; at end of 3 mins at this work level. H.R. 150

3:43 p.m. Walking at 2 mph, level, after 1 min and following 1 min of standing still. H.R. 115

CONTROL EXPERIMENT DAY 13



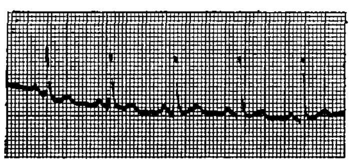
5:25 p.m. Mild exercise, touching toes, at bottom of tank. H.R. 83



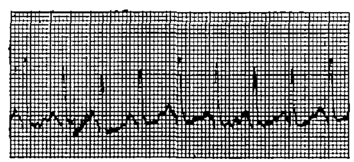
5:35 p.m. Heavy exercise, end of 3 mins flutter kick at bottom. H.R. 166

5:39 pm. 4th min of recovery, subject resting H.R. 103

CVCS EXPERIMENT DAY 14



5:39 p.m. Mild exercise, waving arms, at surface, maximum pressure. H.R. 94



7:06 p.m. Heavy exercise, flutter kick for 3 mins, maximum pressure. H.R. 150

7:09:30 p.m. 4th min. of recovery, subject resting, maximum pressure. H.R. 102

Figure 22: REPRESENTATIVE "NORMAL" EKG RECORDS, RESTING AND WORKING, BEFORE THE EXPERIMENTS AND DURING IMMERSION

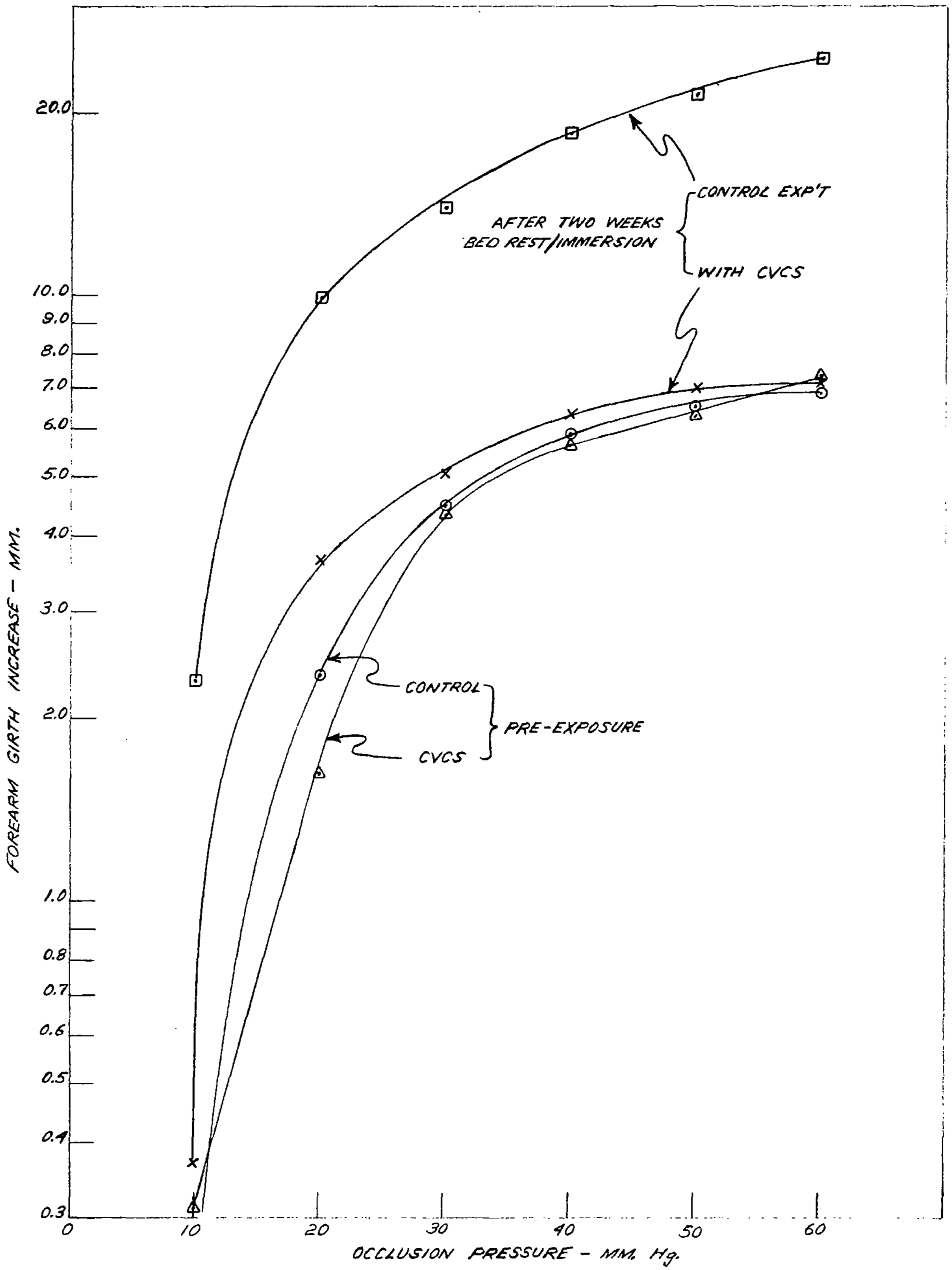


Figure 23: INFLUENCE OF A HYPODYNAMIC ENVIRONMENT ON VASCULAR DISTENSIBILITY, WITH AND WITHOUT THE CVCS

the capacitance vessels were distended sufficiently to cause a 2 millimeter increase in circumference, seven times as much as was observed at the same pressure before the 2-week hypodynamic exposure. At 60 mm. Hg intravascular pressure, the control post-exposure girth increase was 25 millimeters, nearly double the value at 30 mm. Hg; the comparable girth changes in the pre-immersion measurement of the control experiment were 4.5 millimeters at 30 mm. Hg and 6.9 at 60 mm. Hg. The enormous increase in the distensibility, or compliance, of the capacitance vessel system of the arm as a result of the control hypodynamic exposure is contrasted with a slight, possibly insignificant, increase in the CVCS experiment. The maximum difference between pre- and post-exposure determinations in the CVCS experiment is seen at 20 mm. Hg occlusion pressure, where the post-exposure girth increase was double the pre-exposure value. The difference was only 16% at 30 and 40 mm. Hg and was in the reverse direction at 60 mm. Hg. The following table presents the detailed comparisons of control and CVCS experiments at each level of occluding pressure.

TABLE 6

INCREASES IN ARM GIRTH INCREMENT AT EQUAL DISTENSION PRESSURES
following 2 weeks of bed-rest and immersion

Occlusion Pressure mm. Hg	Control Experiment Post-Pre (mm.)	CVCS Experiment Post-Pre (mm.)
10	1.99	0.37
20	7.91	1.87
30	9.83	0.70
40	13.09	0.88
50	14.93	0.45
60	17.25	-0.14

As mentioned earlier, the per-centage change in limb volume, and therefore in venous volume within the limb, at a particular occluding pressure is double the corresponding per-centage change in arm girth. Thus the change in volume when venous transmural pressure was raised from zero to 10 mm. Hg after the control exposure was 14 times as great as for the same increase in distending pressure before the 2-week exposure.

To analyze the time course of venous compliance or vascular distensibility during the CVCS experiment exposure, a single number was required. We have chosen as the parameter or index to represent venous compliance the increase in forearm girth at an intra-vascular (i.e. impeding) pressure of 60 mm. Hg. The evidence from Figure 23 would indicate that this is the most stable of the quantities determined by our technique, and therefore least likely to be significantly influenced by possible random day-to-day influences not directly related to hypodynamic deconditioning. In Figure 24 the values for this index of venous compliance, determined

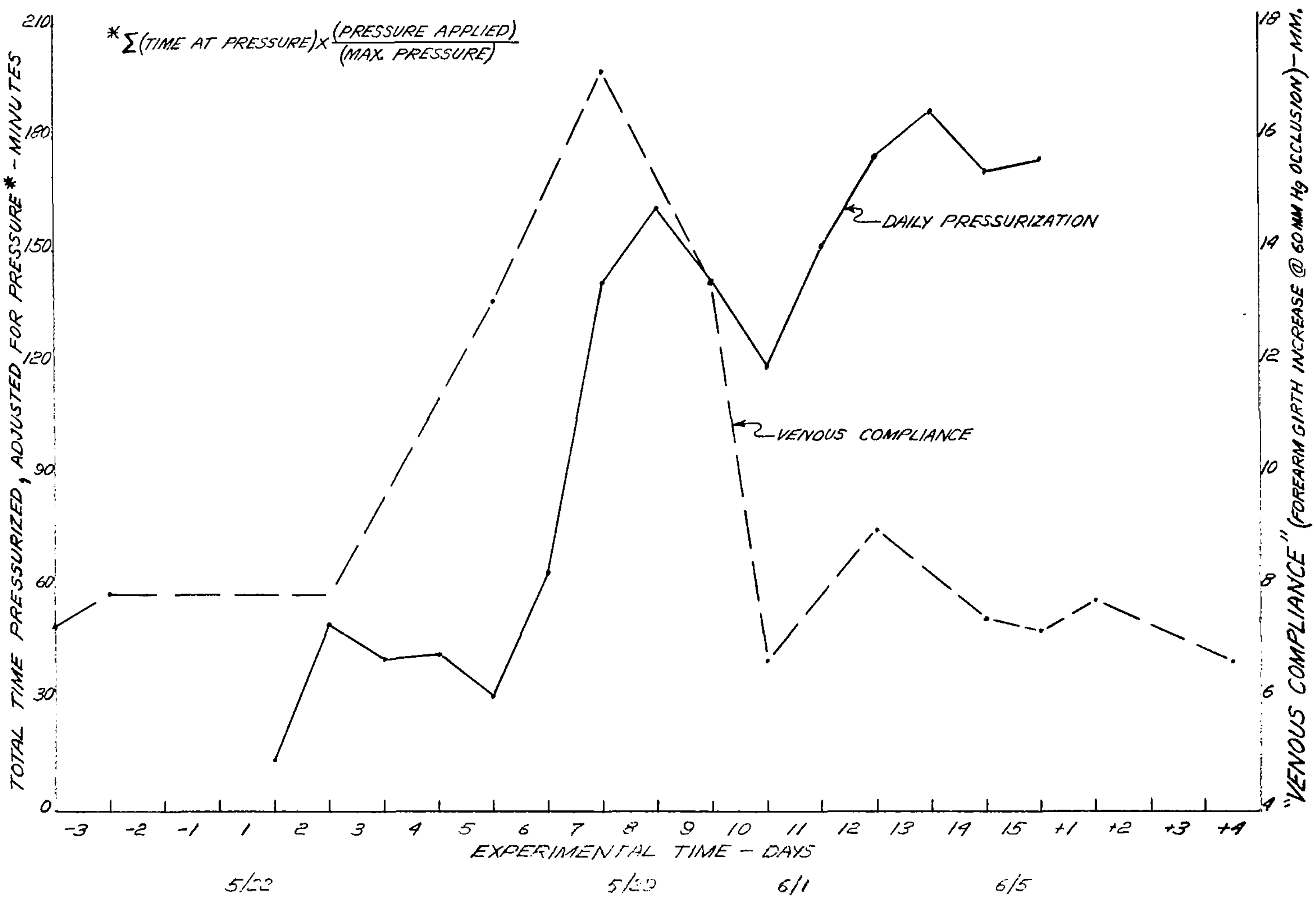


Figure 24: EFFECT OF DAILY DURATION OF CVCS ACTIVATION ON THE VASCULAR RESPONSE

periodically during the CVCS experiment, are shown in comparison with the day-to-day history of effective pressurization time for the suit. It can be seen that for the first 6 days of the hypodynamic exposure, the suit was less than fully pressurized for most of the immersion time, and the venous compliance index increased from the pre-exposure level of less than 8 to more than 17 on the morning of the eighth day, representing a more than 4-fold greater volume increase at 60 mm. Hg distension pressure. This deterioration in venous compliance may be compared with the change from 6.9 to 24.7 observed after the 14-day control experiment.

As Figure 24 shows, the duration and magnitude of suit pressurization had increased by the eighth day so that the effective pressurization time was over two and a half hours (cumulative sum of pressurized time multiplied by the ratio of applied pressure to maximum pressure). At the beginning of the 10th immersion day, the venous compliance index had dropped to 13.4 and on day 11 it fell to half that value,approximating the pre-exposure level. On the last day the index was equal to the pre-exposure value, and remained at essentially this level throughout the recovery period. The data suggest a lag of approximately 24 to 48 hours in the response of venous compliance to suit pressurization. There is also a definite indication that seven days of bed-rest and immersion with minimal suit pressurization effectiveness can produce as much deterioration in venous compliance as 14 days of such treatment without the CVCS but with extensive underwater activity. Finally, the evidence presented in Figure 24 suggests that 2.5 hours per day of full pressure activation of the CVCS for 3 days can reverse a deterioration in venous compliance approximating that produced by 14 days bed-rest and active immersion without vascular aids.

It is of incidental interest to note the close similarity between the two pre-exposure curves of vascular distensibility in Figure 23, and the near-identity of the selected index value taken at 60 mm. Hg occlusion pressure. There was a gap of almost 3 months between these two determinations; the results suggest that this technique of measurement produces a rather reliable and stable parameter.

Nutrition and water balance.--Table 7 displays the daily intake and output of fluid for both experiments together with the daily nude weight. It is apparent that no consistent changes occurred in water content of the body. The detailed daily food intake for the control and CVCS experiments are given respectively in Tables 8 and 9. As can be seen, the subject's appetite remained quite good throughout both experiments and he reported being quite satisfied with the food selection. He insisted in consuming rather substantial quantities of milk although discouraged to do so. Figure 25 presents the daily urinalysis data, the most prominent feature of which is the high sustained output of calcium.

Hematology.--Partly as a result of the subject's strong objection to the blood sampling procedure (and our concern to maintain his state of morale at a high level) and partly because of accidents at the commercial laboratory which performed the tests, there are relatively few blood analysis data to report. Table 10 presents these data; there are no particularly unusual features, although there appears to be a trend in both experiments for hematocrit to decrease with increasing exposure duration. The sedimentation rates in the control experiment appear somewhat high after the second day; for reasons which we are unable to explain, the laboratory did not report sedimentation rate or calcium in the CVCS experiment, nor RBC counts at any time.

Table 7

FLUID AND WEIGHT BALANCE

EXPERIMENT DAY	FLUID INTAKE (ml)	FLUID OUTPUT (gms)	NUDE WEIGHT (lbs)
	A: CONTROL EXPERIMENT		
1	1313	1275	156.63
2	1220	976	
3	1290	536	
4	1520	1523	157.21
5	1410	1128	157.40
6	1900	1290	158.26
7	2060	1440	
8	1795	890	
9	1480	1000	157.01
10	1710	1100	157.52
11	1365	1020	157.47
12	1620	1100	157.95
13	1748	1250	157.79
14	1315	1100	157.03
Average	1553	1116	157.43
R_1	2580	410	155.25
R_2	2320	1250	
R_3	2140	680	155.06
Average	2347	780	155.16
	B: SUITED EXPERIMENT		
1	2460	1110	159.14
2	1862	1901	158.85
3	1770	1071	159.70
4	1920	1984	158.87
5	1819	1215	159.90
6	1578	983	160.40
7	2255	1431	158.69
8	1630	1276	159.55
9	1670	1374	160.24
10	2276	1604	160.39
11	1926	1979	159.75
12	1850	1069	159.16
13	1820	1700	159.10
14	1774	1330	158.89
15	2345	1331	160.33
Average	1930	1424	159.53
R_1	2300	1608	161.82
R_2	2638	2531	
R_3	1384	1082	
Average	2107	1740	

TABLE 8

DAILY INTAKE OF FOOD AND BEVERAGES , Control Experiment

DATE	BREAKFAST	LUNCH	TV DINNER	SNACKS	TOTAL MILK	TOTAL COFFEE	TOTAL FLUIDS
Mon. 2/27			17 oz. steak dinner 2 slices bread 473 cc milk	3 1/2 tsp. sugar in coffee	513 cc	900 cc	1413 cc
Tues. 2/28 1st Day	2 eggs 3 sausages (3oz.) 2 slices toast 1 tsp. sugar 175 cc coffee	4 oz. lean beef 2 slices rye bread 1 tsp. sugar 200 cc coffee 10 cc milk	11 oz. chicken dinner 1 slice bread 2 tsp. butter 250 cc milk	2 plain donuts 1 peanut butter sandwich 1 tsp. sugar in coffee	278 cc	905 cc	1313 cc
Wed. 3/1 2nd Day	2 eggs 4 sausages (4 oz.) 2 slices toast 1 tsp. butter 140 cc coffee	1 beef sandwich 1 oz. potato chips 200 cc milk	17 oz turkey dinner 1 slice bread 1 tsp. butter	410 cc cola 1 tsp. sugar in coffee 1 donut	210 cc	600 cc	1220 cc
Thurs. 3/2 3rd Day	2 eggs 4 strips bacon 2 slices toast 170 cc milk	1 barbequed beef sandwich	11 oz. meat loaf dinner 2 slices bread 3 tsp. butter 2 pecan pies 250 cc coffee 2 tsp. sugar 190 cc milk	3 tsp. sugar in coffee 150 cc cola 130 cc orange juice	385 cc	625 cc	1290 cc
Fri. 3/3 4th Day	2 eggs 4 strips bacon 1 sweet roll 1 tsp. butter 150 cc coffee 110 cc orange juice	none	12 oz. shrimp chow-mein dinner 1 slice bread 1 tsp. butter 1 pecan pie 170 cc milk	2 slices bread 3 Tbs. peanut butter 4 tsp. sugar in coffee 1 sandwich	430 cc	980 cc	1520 cc
Sat. 3/4 5th Day	2 eggs 4 slices bacon 1 sweet roll 1 tsp. butter 1 tsp. sugar 150 cc coffee 120 cc orange juice	1 beef sandwich 1 oz. potato chips 1 pickle 170 cc milk	11.5 oz. macaroni & beef cole slaw 2 slices bread 2 tsp. butter 170 cc milk	2 tsp. sugar in coffee 1 brownie	360 cc	820 cc	1410 cc
Sun. 3/5 6th Day	4 slices bacon 1 sausage (1 oz.) 2 slices toast 1 tsp. butter 200 cc coffee 150 cc orange juice	peanut butter sandwich 340 cc milk	11.5 oz. beef short-ribs (ate half) 2 vegetables 1 tsp. sugar 170 cc coffee 10 cc milk	4 tsp. sugar in coffee 150 cc water	560 cc	1020 cc	1900 cc
Mon. 3/6 7th Day	3 strips bacon 2 slices toast 1 tsp. butter 300 cc grapefruit juice 400 cc coffee	none	8 oz. spaghetti & beef 5 oz. leftover ribs 170 cc milk	3 tsp. sugar in coffee 270 cc water	360 cc	1130 cc	2060 cc

DATE	BREAKFAST	LUNCH	TV DINNER	SNACKS	TOTAL MILK	TOTAL COFFEE	TOTAL FLUID
Tues. 3/7 8th Day	3 eggs 2 slices toast 1 sweet roll 1 Tbs. butter 170 cc coffee 160 cc coffee 160 cc juice	none	12 oz. chicken 2 vegetables 1 slice bread 2 tsp. butter 180 cc milk	4 tsp. sugar in coffee	215 cc	1090 cc	1795 cc
Wed. 3/8 9th Day	3 eggs 1 sweet roll 2 slices toast 1 tsp. butter 200 cc coffee 100 cc orange juice	1 BBQ beef 1 oz. potato chips 170 cc milk	17 oz steak 2 vegetables 1 slice bread 2 tsp. butter	3 tsp. sugar in coffee	380 cc	820 cc	1480 cc
Thurs 3/9 10th Day	3 eggs 4 sausage 2 slices toast 1 Tbs. butter 1 tsp. sugar 160 cc orange juice 190 cc coffee	2 slices cheese 3 slices bologna 4 slices bread mayonaise lettuce 200 cc milk	15 1/2 oz seafood 2 vegetables 1 slice bread 1 tsp. butter	2 1/2 tsp. sugar in coffee 100 cc water 3 Life Savers luncheon meat sandwich	320 cc	1130 cc	1710 cc
Fri. 3/10 11th Day	3 eggs 3 sausages 2 slices toast 220 cc grapefruit 200 cc coffee	pimiento loaf sandwich applesauce cheese 160 cc cola	11.5 oz ribs of beef 2 slices bread 180 cc milk 2 tsp. butter	4 tsp. sugar in coffee apple pie	215 cc	770 cc	1365 cc
Sat. 3/11 12th Day	3 eggs 3 sausages 2 slices toast 1 Tbs butter 180 cc coffee 1 tsp. sugar 230 cc orange juice	1 donut 100 cc milk	11 oz meatloaf dinner 180 cc milk 2 slices bread 3 tsp. butter	4 1/2 tsp. sugar in coffee bologna & cheese sandwich 40 cc water	490 cc	900 cc	1620 cc
Sun. 3/12 13th Day	2 eggs 3 sausages 2 slices toast 1 Tbs. butter 180 cc coffee 130 cc vegetable juice 220 cc orange juice	bologna sandwich w/ mayonaise 2 slices bread 100 cc coffee 20 cc milk	16 oz breast of chicken coleslaw 180 cc milk 1 slice bread 1 Tbs. butter 180 cc coffee 10 cc milk 1 1/2 tsp. sugar	2 1/2 tsp. sugar in coffee 50 cc water 130 cc grapefruit juice	240 cc	978 cc	1748 cc
Mon. 3/13 14th Day	3 eggs 1 sausage 2 pieces toast 1 Tbs. butter 1 tsp. sugar 170 cc grapefruit juice 170 cc coffee	bologna sandwich w/lettuce & mayonaise 2 donuts	17 oz turkey dinner	170 cc grapefruit juice	--	975 cc	1315 cc

TABLE 9

DAILY INTAKE OF FOOD AND BEVERAGES, CVCS Experiment

DATE	BREAKFAST	LUNCH	TV DINNER	SNACKS	TOTAL MILK	TOTAL COFFEE	TOTAL FLUIDS
Mon. 5/22 1st Day	3 eggs 2 sausage 1 slice toast 1 Tbs. butter 240 cc orange juice 160 cc coffee 1 tsp. sugar 10 cc milk	300 cc milk 2 beef and cheese sandwiches w/ mayonaise	400 cc milk turkey dinner 2 slices bread 2 Tbs. butter	350 cc water 90 cc water	710cc	1070cc	2460cc
Tues. 5/23 2nd. Day	2 eggs 3 sausages 2 slices toast 120 cc orange juice 170 cc coffee	1 1/2 bologna & cheese sandwiches w/lettuce 200 cc milk	310 cc coffee beef dinner 2 slices bread 2 Tbs. margerine 200 cc milk	160 cc cola 160 cc water bologna & cheese sandwich w/ lettuce, mayon.	400cc	1022cc	1862cc
Wed. 5/24 3rd Day	2 eggs 2 sausages 2 slices toast 1 Tbs. butter 160 cc coffee 160 cc orange juice	BBQ beef sandwich 200 cc milk	Salisbury steak dinner 2 slices bread 2 Tbs. margerine 200 cc milk	1 tsp. sugar in coff. 10 cc half & half in coffee 160 cc grapefruit juice	410cc	1050cc	1780cc
Thurs. 5/25 4th Day	shredded wheat 300 cc milk 180 cc grapefruit juice 4 tsp. sugar 180 cc coffee	bologna sandwich w/ mayonaise, lettuce, mustard 200 cc milk	fried chicken dinner 200 cc milk 2 slices bread 2 Tbs. margerine	1 tsp. sugar in coff 20 cc milk in coffee bologna sandwich w/ lettuce, mayonaise 160 cc cola	720 cc	880cc	1940cc
Fri. 5/26 5th Day	2 eggs 3 sausages 2 slices toast 1 Tbs. butter 170 cc coffee 160cc grapefruit juice	bologna & cheese sandwich w/mayonaise, lettuce, mustard 200 cc milk	17 oz turkey dinner 2 slices bread 2 Tbs. margerine 200 cc milk	1/2 tsp. sugar in coffee 10 cc milk in coffee 355 cc cola 224 cc cola	410 cc	670 cc	1819 cc
Sat. 5/27 6th Day	2 waffles 2 Tbs. butter 4 sausages syrup, 160 cc grape-fruit juice 180 cc coffee	bologna & cheese sandwich corned beef sandwich w/ lettuce 219 cc milk	17 oz Salisbury steak dinner 2 slices bread 2 Tbs. margerine 200 cc coffee	1 tsp. sugar in coffee 10 cc cream in coffee 324 cc cola	229 cc	875 cc	1588 cc
Sun. 5/28 7th Day	2 eggs 3 sausages 2 slices toast 1 Tbs. butter 180 cc coffee 1 tsp. sugar 160 cc grapefruit juice	2 bologna & cheese sandwiches w/ mayonaise, mustard 350 cc milk	15 1/2 oz seafood dinner 1 slice bread 1 Tbs. margerine 200 cc milk	10 cc milk in coffee 10 cc milk " " 2 tsp. sugar " " 1 tsp. sugar " " 15 cc milk in coffee	585 cc	1510 cc	2255 cc
Mon. 5/29 8th Day	170 cc orange juice 180 cc grapefruit juice	tuna salad sandwich 200 cc chocolate milk	11oz meatloaf dinner 2 slices bread 2 Tbs. margerine 200 cc milk	180 cc milk corned beef w/ cheese sandwich peanut butter w/ mayonaise sandwich 10 cc milk in coffee 100 cc cola	590 cc	590 cc	1630 cc
Tues. 5/30 9th Day	2 eggs 3 slices bacon 2 waffles 2 Tbs. butter 170 cc grapefruit juice 180 cc coffee	meat & cheese sandwich w/ mayonaise& lettuce 200 cc milk	10 3/4 oz. noodle & chicken dinner 2 slices bread 2 Tbs. margerine 200 cc milk 200 cc coffee	peanut butter sandwich 200 cc milk 150 cc water meat & cheese sandwich w/ mayonaise, lettuce 170 cc milk 336 cc cola	600 cc	790 cc	1880 cc
Wed. 5/31 10th Day	2 eggs 4 slices bacon 160 cc grapefruit juice 180 cc coffee 2 slices toast 1 Tbs. butter	vegetable soup 200 cc milk peanut butter sandwich	11 oz fried chicken dinner 1 slice bread 1 Tbs. margerine 200 cc milk	liver sausage sandwich w/ mayonaise, lettuce 170 cc milk 336 cc cola	570 cc	930cc	1966 cc
Thurs. 6/1 11th Day	2 eggs 2 slices toast 3 slices bacon 200 cc grapefruit juice 200 cc coffee	pastrami sandwich 200 cc milk	16 oz beef dinner 2 slices bread 2 Tbs. margerine 200 cc milk 200 cc coffee	1 tsp. sugar in coffee 326 cc cola	400 cc	1000 cc	1926 cc
Fri. 6/2 12th Day	2 waffles 2 Tbs. butter syrup 5 slices bacon 180 cc coffee 160 cc grapefruit juice	bologna & cheese sandwich w/ mayonaise & lettuce 200 cc milk	17 oz. turkey dinner 1 slice bread 1 Tbs. margerine 200 cc milk	200 cc cola 160 cc grapefruit juice	400 cc	930 cc	1850 cc
Sat. 6/3 13th Day	1 egg 3 waffles 3 sausages 1 Tbs. butter syrup 180 cc coffee 160 cc grapefruit juice	200 cc milk 2 salami & cheese sandwiches w/ mustard, lettuce & mayonaise	17 oz Salisbury steak dinner 2 slices bread 2 Tbs. margerine 200 cc milk	bologna, salami, & cheese sand-which w/ mayonaise 180 cc milk 15 cc milk in coffee 1 tsp. sugar " " 160 cc grapefruit juice	595 cc	905 cc	1820 cc
Sun. 6/4 14th Day	2 eggs 5 strips bacon 2 slices toast 1 Tbs. butter 180 cc coffee 160 cc grapefruit juice	corned beef sandwich w/ mayonaise & lettuce 50 cc dietetic beverage	11 oz. fried chicken dinner (no dessert) 2 slices bread 2 Tbs. margerine 355 cc cola 240 gms chili con carne	1 tsp. sugar in coff. 1 tsp. cremora in coffee 324 cc cola	0 cc	885cc	1774 cc
Mon. 6/5 15th Day	2 eggs 5 strips bacon 2 waffles 2 Tbs. butter syrup 190 cc coffee 160 cc grapefruit juice	hamburger sandwich french fried potatos 150 cc coffee	17 oz. Salisbury steak dinner 2 slices bread 2 Tbs. margerine 200 cc milk	5 cc half & half in coffee 20 cc half & half in coffee 2 tsp. sugar in coffee	225 cc	1960cc	2345 cc

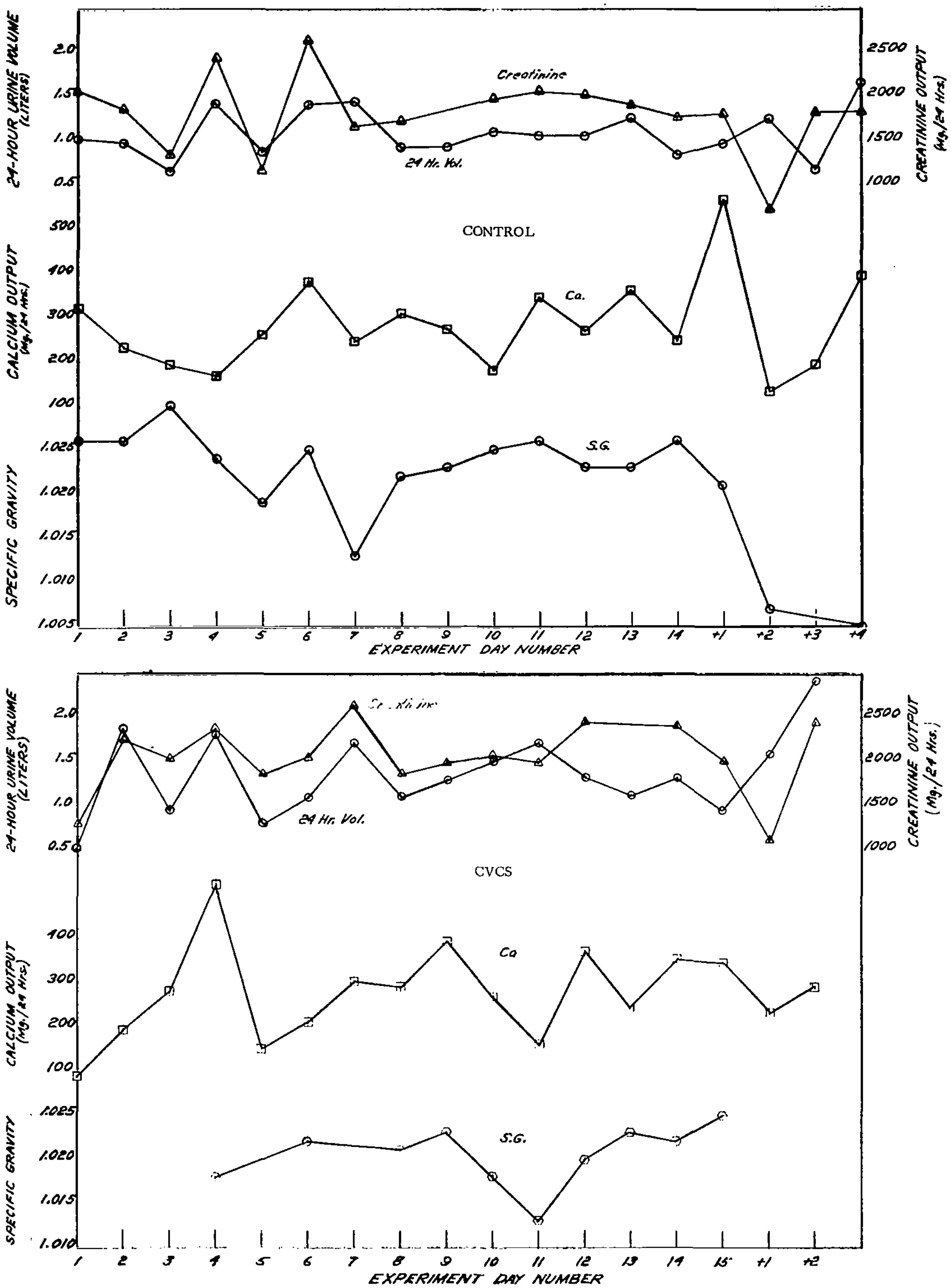


Figure 25: URINALYSIS RESULTS, CONTROL AND CVCS EXPERIMENTS

Table 10

HEMATOLOGY DATA

Exp't Day	Hb $\frac{grams}{100\ ml}$	Hematocrit %	MCHC* $\frac{grams}{100\ ml}$	White Blood Cells $\frac{10^3}{mm^3}$	Sed. Rate $\frac{mm}{hr}$	Serum Calcium $\frac{meq}{liter}$	White Cells, Percent Seg.	Stab	Lymph	Mono	Eosin
CONTROL EXPERIMENT											
2	15.8	48	33.0	9.9	4	QNS					
8	17.0	48	36.0	8.4	17	4.9	64	6	19	8	3
10	16.0	45	35.5	7.2	17	5.2	64	2	27	3	3
R_1**	15.5	44	35.0	9.5	11	5.0	58	1	32	3	6
SUITED EXPERIMENT											
8	17.0	49	34.5	9.5			69	0	24	3	4
13	17.2	48	36.0	10.0			60	1	30	7	2
15	16.4	46	35.6	9.7							

*Mean Corpuscular Hemoglobin Concentration
**First Recovery Day

Although the attending physician performed the Evans Blue procedure for measuring blood volume at the beginning and end of both experiments, only one determination was successfully completed by the laboratory, the other samples being reported as clotted or hemolysed. The one reportable measurement, made on the morning of the 14th immersion day of the control experiment was 6428 ml.

Physiological response to pressurization of the CVCS.--No particular effects of pressurization were discernible in the heart rate or EKG data, and no sensations were reported by the subject other than those associated with the altered respiratory mechanics and the "squeeze" of the suit. The man lay motionless in neutral buoyancy for long periods while fully pressurized, and even slept quite soundly for one period of about half an hour. At no time did he report any symptoms which might be attributed to reduced venous return or excessive blood pooling, with the one exception that his hands frequently felt as though they were being "pulled" at the wrist. This sensation was usually relieved by re-adjusting the area of contact of the wrist bladder.

Figure 26 presents a series of samples of the EKG records taken during and between pressurized periods on the final day of the CVCS experiment. These are typical of records taken throughout the experiment, and show no effects of suit actuation. They also show no consistent differences from traces taken during the control experiment. (Figure 22)

Peripheral Pulse (Pulse Wave Velocity).--Table 11 is a summary of the pulse wave interval data taken during both the control and CVCS experiments. While data were not collected on every experiment day there is ample evidence to reveal any trends in the readings which might be present. None can be seen. There appears to be no correlation between the pulse wave interval and time, degree of de-conditioning, or amount of pressurization. There was an increase in the pulse interval, thus a decrease in the pulse wave velocity, during the post-control experiment tilt test which was not duplicated in the post-CVCS tilt but this information by itself cannot be considered highly meaningful. It is interesting to note, however, that during the latter test the heart rate went from 61 to 88 with the pulse wave interval constant.

Figure 27 shows a series of simultaneous EKG and peripheral pulse waveforms taken while the subject was asleep in the water under full pressurization. Note the rounded character of the peripheral pulse at 17:15 and the distinct change two minutes later; the fact that he wakened 7 minutes after this change occurred suggests the possibility of a relationship with the waking process. The rounded shape is indicative of a very flaccid arterial path; this type of waveform was not duplicated at any other time in either experiment.

Rather long pulse wave intervals were recorded on the 11th day of the CVCS experiment with the subject reporting "unusual breathing comfort", and on the 15th day of the same experiment. It might be reasoned that the subject would have a feeling of well-being on the last day of a long and rather arduous experiment, which would be psychologically similar to an improvement in comfort. If the speculation is valid, it suggests that reduced pulse wave velocity might be associated with the absence of tension and the presence of pleasant feelings.

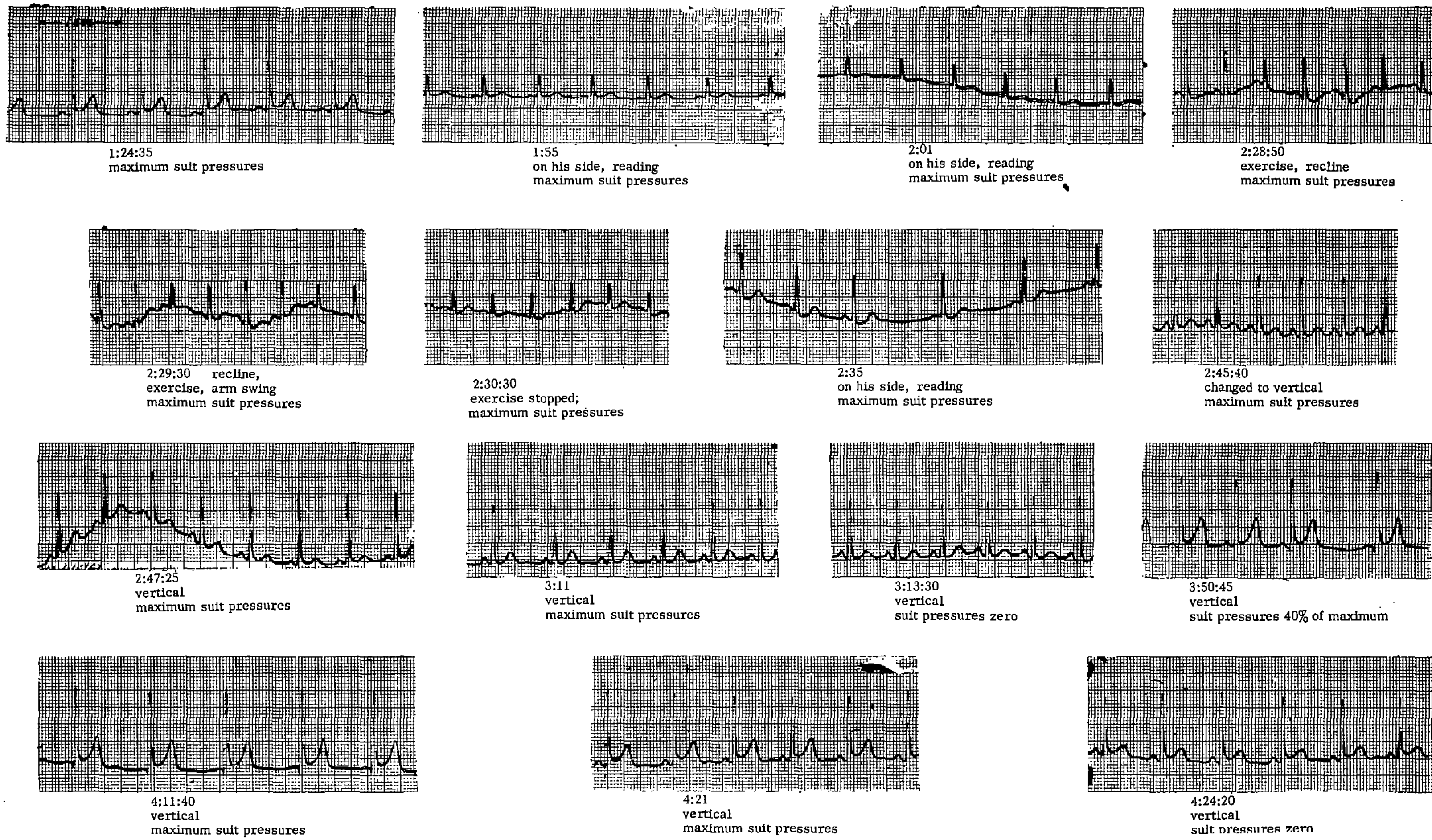


Figure 26: EKG TRACINGS TAKEN DURING PRESSURIZATION OF THE CVCS DURING THE 15th IMMERSION DAY, CVCS EXPERIMENT

Table 11

PULSE WAVE INTERVAL* DATA

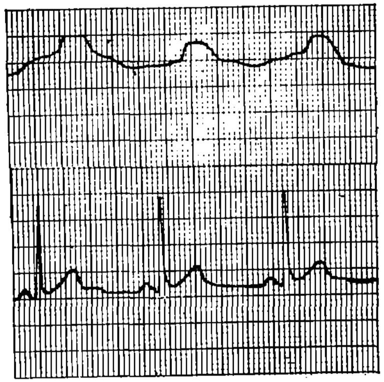
CONTROL EXPERIMENT

Exp. Day	Time	Interval (ms)	Heart Rate	Activity
0	18:11	165	73	Supine in instrumentation room
5	15:00	170	94	Supine, in trailer getting dressed
	17:39	170	68	Erect, bottom of tank
6	16:31	180	75	Horizontal, bottom of tank
9	15:32	180	78	Erect, bottom of tank
12	12:53	160	65	Supine, at top of tank ready for immersion
	14:49	160	100	Horizontal, bottom of tank
13	10:18	145	78	Supine, in trailer ready for tank
14	14:00	160	64	Supine, 4 feet from bottom of tank
	16:33	150	70	Erect, bottom of tank
	18:03	155	58	Supine, on tilt table at 0°, 25 minutes before tilt test
	18:37	180		Supine, 9 minutes after tilt to 70°
	19:12	160		Supine, on tilt table 33 minutes after return to horizontal

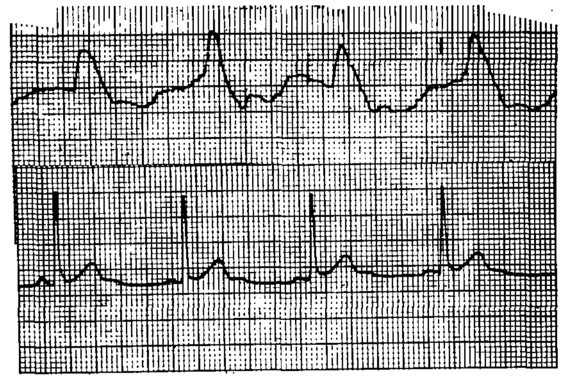
CVCS EXPERIMENT

Exp. Day	Time	Interval (ms)	Heart Rate	External Pressure (% of max)	Activity
3	17:07	170	91	40	Horizontal, immersed
5	18:05	160	62	0	Erect, immersed
6	18:20	170	60	80	Horizontal, immersed
	18:24	170	60	80	Horizontal, immersed
9	17:15	180	61	100	Horizontal, immersed, asleep
	17:17	180	65	100	Horizontal, immersed, asleep
	17:24-	165	71	100	Horizontal, immersed, 3 seconds before awakening
	17:24+	160	71	100	Horizontal, immersed, 3 seconds after awakening
11	14:33	180	64	40	Horizontal, immersed
	17:17	200	65	100	Erect, immersed, subject noted unusual breathing comfort
14	13:10	160	58	0	Horizontal, immersed, post mild exercise
	13:31	160	81	100	Horizontal, immersed
	14:04	180	76	100	Horizontal, immersed
	15:38	170	81	0	Erect, immersed, going to bottom
	15:49	170	94	100	Erect, immersed, at bottom
	19:00	180	77	0	Supine, on litter at surface
15	13:55	140	83	100	Horizontal, immersed, 1 minute post exercise
	14:47	195	103	100	Horizontal, immersed, post exercise
	16:25	180	91	100	Erect, immersed
	17:42	200	61		Supine, on tilt table at 0°, 5 minutes before tilt
	17:49	200	70		Supine, 2 minutes after tilt to 70°
	18:06	200	88		Supine, 19 minutes after tilt to 70°
	18:08-	200	67		Supine, 30 seconds after return to horizontal

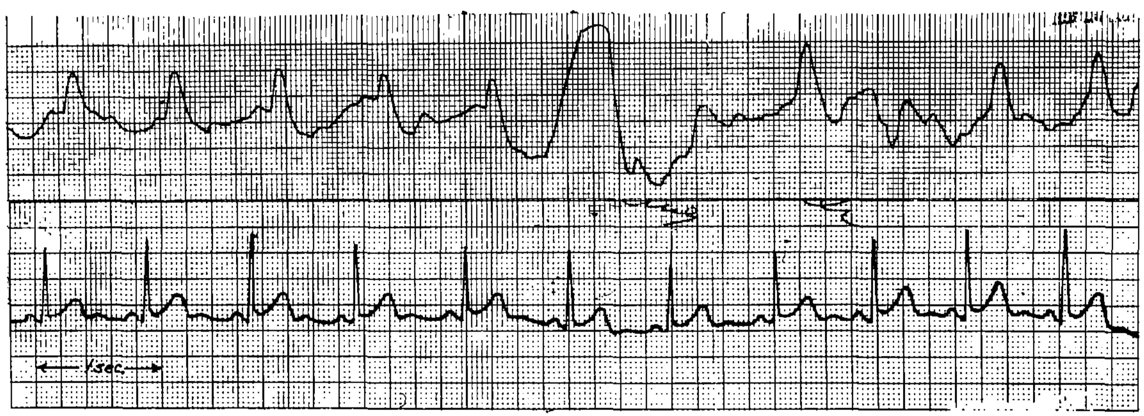
*Time from the R-wave peak of the EKG to the onset of the main wave of the peripheral volume pulse



5:15 p.m. Asleep for approximately the past 10 minutes, floating in neutral buoyancy.



5:17 p.m. 7 minutes before awakening.



5:24 p.m. Just before and immediately after awakening. Awoke at 5:24:01 when rocked by a wave.

*Upper trace is recorded from impedance electrodes above and below the left elbow; lower trace is the simultaneously recorded EKG from bi-polar chest leads.

Figure 27: PERIPHERAL VOLUME PULSE*, ASLEEP AND AWAKE IMMERSED SUIT FULLY PRESSURIZED, CVCS EXPERIMENT DAY 9

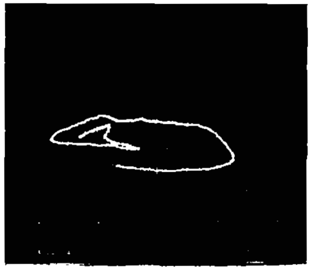
Vector Impedance Cardiograms (VIC). --Interpretation of the data cannot be completed without the acquisition of additional base-line data on the effects of immersion, posture, and pressure-breathing, in which the effect is a reduction in area of the loop, without a deviation in the loop major axis.

Figure 29 shows an almost 90° deviation of the loop axis, from horizontal to vertical, when the subject was tilted from zero to 70° several days after the CVCS experiment.

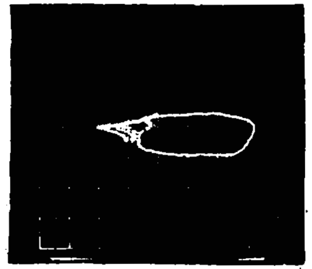
Figure 30 contains several examples of VIC loops taken with and without the CVCS, identified by date and posture in the water. In the first five traces, three from the control and two from the CVCS experiment, the major lobe is almost entirely oriented along the horizontal axis. Further, the trace remains basically the same regardless of the orientation of the body in the water and has the same general characteristics as to the major axis as those taken supine at 1G (see Figure 29). The last three traces, taken while pressurized, have substantial portions of the trace in the vertical axis and in this respect are comparable to the traces in Figure 29 which were taken at a 70° tilt at 1G.

Medical evaluation of the experiments. --(prepared by R. P. Uller, M. D., team physician) After observing the subject during the control and experimental periods one thing is quite obvious. There was a definite preservation of cardiovascular responses to tilt-table testing in the experimental period (period when the suit to prevent cardio-vascular deconditioning was used). This is to be compared to the obvious cardio-vascular deconditioning that was present on tilt-table testing after the control period (as manifested by tachycardia followed by hypotension, bradycardia and near syncope). The elevation of diastolic blood pressure, the moderate heart rate and absence of subjective symptoms of pre-syncope is very good evidence that during the experimental period vascular tone or responsiveness remained intact.

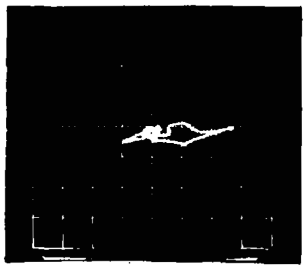
The comparison of venous compliance between the two periods shows a noticeable difference, which might be interpreted as further evidence of good vascular tone during the experimental period.



Breathing Pressure - 8.5 in. H_2O
(below reference level)



Reference level breathing pressure
selected by subject as "balanced"



Breathing Pressure +6.5 in. H_2O
(above reference level)

Breathing Pressure + 13 in. H_2O
(above reference level)

Breathing Pressure + 19.5 in. H_2O
(above reference level)

Figure 28: EFFECT OF PRESSURE BREATHING ON THE VECTOR IMPEDANCE CARDIOGRAM
WHILE SUBMERGED (with no counter-pressure, control experiment)

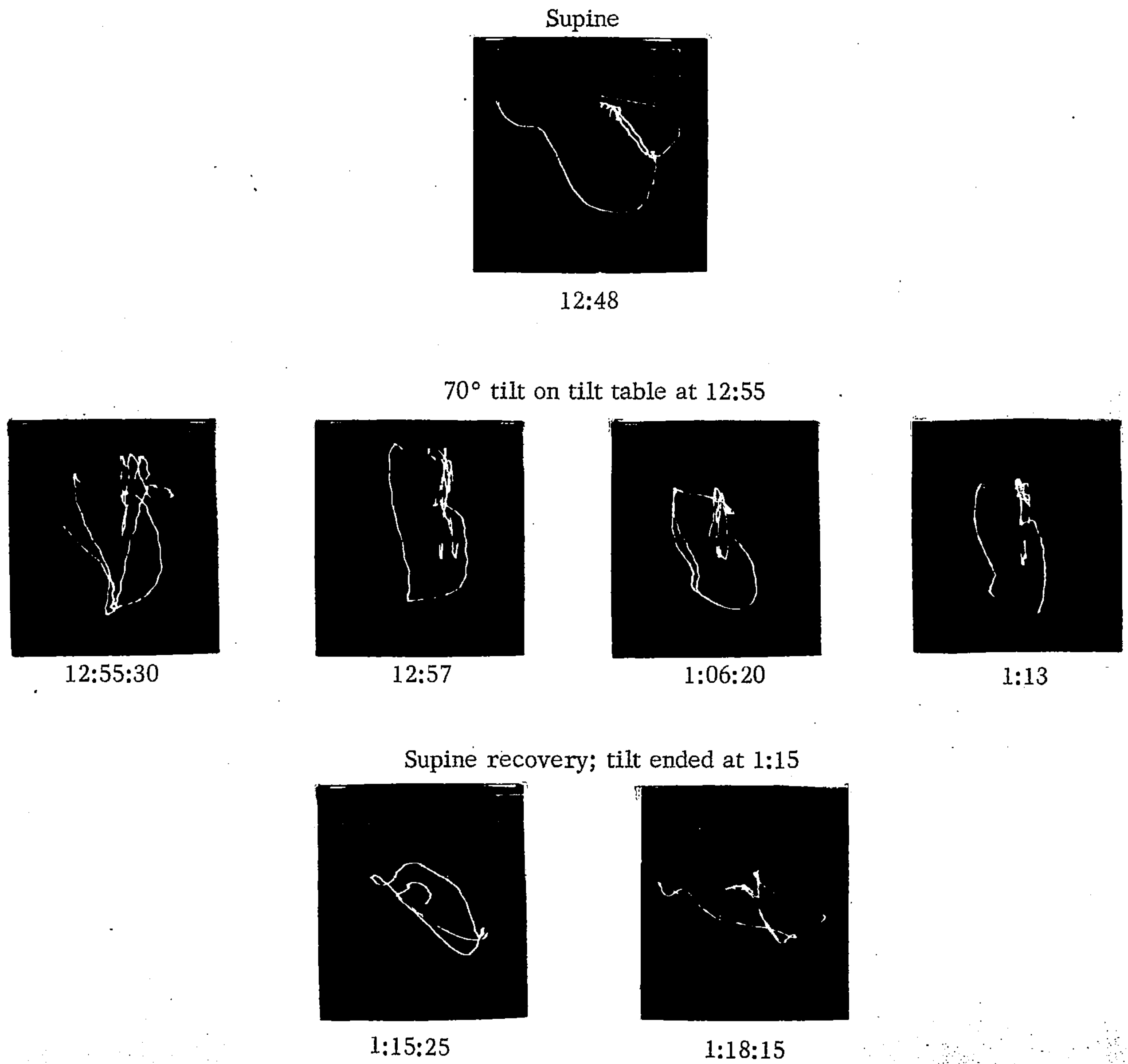
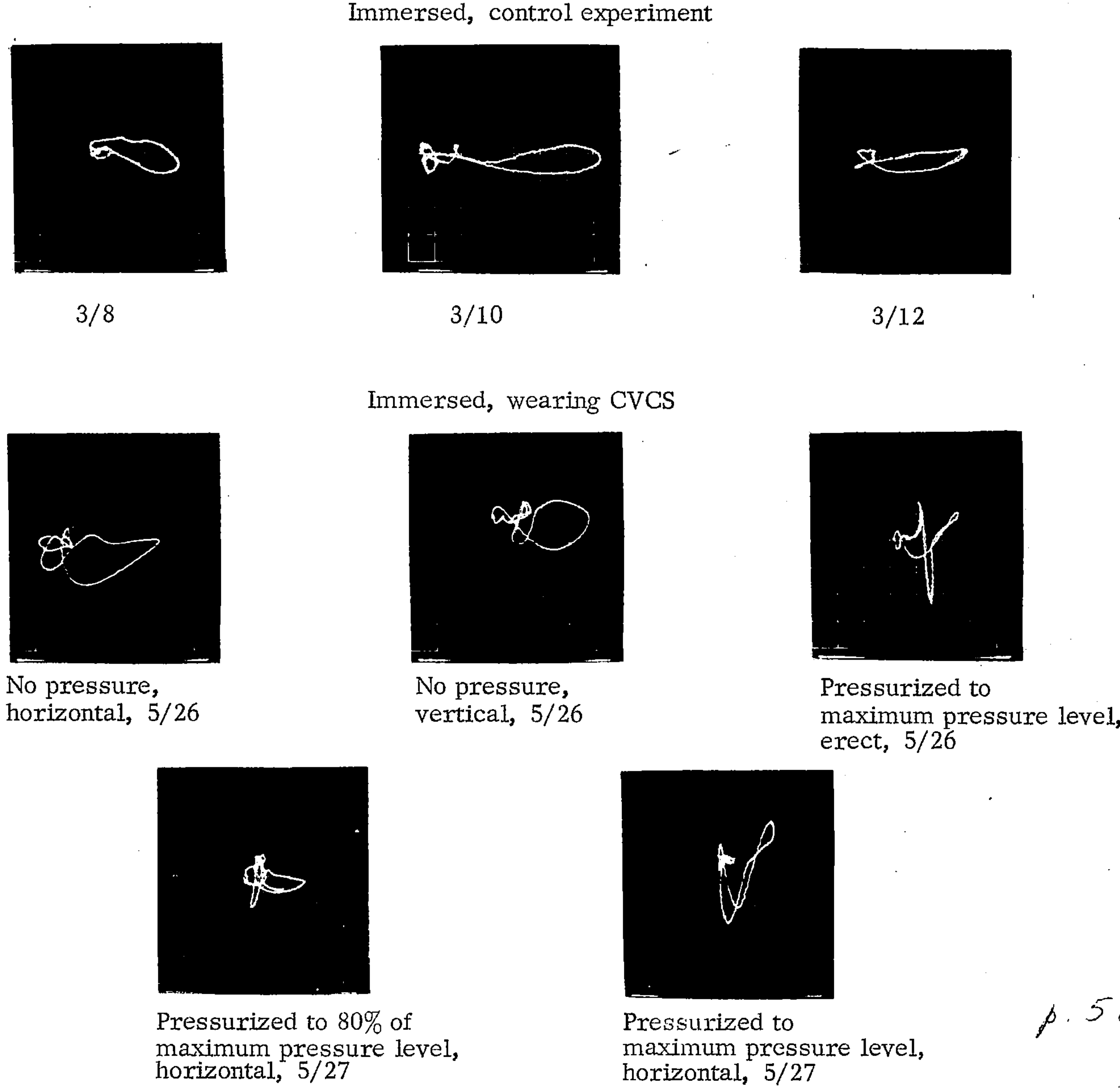


Figure 29: EFFECT OF A 70° TILT ON THE VECTOR IMPEDANCE CARDIOGRAM
(4th recovery day following the CVCS experiment, 6/9/67)



p. 58

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Figure 30: VECTOR IMPEDANCE CARDIOGRAMS DURING IMMERSION WITH AND WITHOUT THE CVCS

DISCUSSION

Although the evidence is far from complete, there are no indications in the available data to suggest that a significant change in plasma volume occurred in either experiment. The reductions in hematocrit which occurred in both exposures appear to be relatively modest and possibly not significant. There was no detectable diuresis, overall weight and water balance being maintained rather well throughout both 2-week hypodynamic exposures. It is probably reasonable to suppose that the absence of changes in these parameters is the result of the care taken to maintain a slightly positive breathing pressure throughout the immersion periods in both control and CVCS experiments. This conclusion would be in accord with explanations which have been offered for the water loss in space flights and in early immersion tests with normal SCUBA gear, these explanations being based on altered pressure-stretch relationships within the pulmonary system. (see ref. 8)

If the foregoing view is correct, we may conclude that we were reasonably successful in our attempt to eliminate water balance shifts as a factor in the deconditioning influence of our experimental environment of bed-rest combined with immersion.

Our second aim, to eliminate the factor of enforced inactivity without imposing an artificial regimen of prescribed exercise, was less successfully realized. However, the failure to match the activity pattern in the CVCS exposure to that observed in the control experiment, actually enhances the argument in support of the suit's anti-deconditioning efficacy, in that the observed improvement in tolerance for the hypodynamic environment when the suit was worn was achieved in spite of a greatly reduced activity level during immersion as compared with the control conditions.

It is worth emphasizing that severe deconditioning occurred without the suit even though the subject used his skeletal muscles and the bones of his limbs daily during immersion to support weight and resist the inertial forces created in jumping, kicking, etcetera. On the other hand, the signs of deconditioning were either absent or greatly attenuated when the CVCS was worn, even though the bearing of weight by the legs occurred only very briefly once or twice during the 2-week period and the occasional exercise consisted of little more than "limbering-up", involving no inertia nor resistive forces other than the restrictions of the pressurized suit itself.

The only distinct signs of deterioration in the CVCS experiment relate to problems of recovery from severe exercise, or what is generally termed, loosely, "fatigue factors". If one is willing to discriminate between "cardiovascular de-conditioning" and other kinds of de-conditioning relating to the ability to endure hard work or recover quickly from severe work loads, one is led to the tentative conclusion that the action of the suit in the CVCS experiment effectively prevented the former, while the relative lack of muscular exercise was responsible for the presence of the latter during the recovery days. To explore this possibility, let us consider the elements in cardiovascular responsiveness on the one hand, and work endurance on the other.

In our view, cardiovascular responsiveness is illustrated best in the type of test which imposes a sudden transient load on the circulatory system, to which an adaptive response is necessary. The character of the response then serves as an indication of the responsiveness of the cardiovascular system, particularly its regulatory or control aspects, as distinguished from basic capacities, capabilities, limits or other fundamental measures of the system. Within this context, the CVCS is considered as a device aimed at preserving responsiveness in the cardio-vascular system, not something which can change capacity for work or endurance. It follows that the slightly reduced work capacity at the end of the control exposure can be interpreted as a reflection of the minor importance of "cardiovascular responsiveness" in determining the ability for maximal work on the bicycle. Similarly, the slight improvement in work capacity at the end of the CVCS exposure can be interpreted as confirming the modest advantage of preserving cardiovascular responsiveness. Conversely, the delayed return of EKG pattern to normal following the work capacity test and the elevated heart rate during all states of activity on the CVCS recovery days can be interpreted as a reflection of a deterioration, during exposure, of the general physical fitness. In other words, using the terminology of athletics, we might say that the subject was "out of condition" as a result of his CVCS hypodynamic exposure, due to inadequate exercise, but showed unimpaired cardiovascular responsiveness in terms of orthostatic tolerance and ability to compensate appropriately for sudden increases in load, imposed for limited durations.

Being out of condition in respect to muscle training yet with the same cardiac and respiratory capacity for oxygen transport as before the hypodynamic exposure, the subject apparently paid an excessive physiological penalty in order to complete the post-exposure ergometer test of work capacity, in terms of anaerobic metabolism and consequent accumulations of metabolic products. In this view, the high heart rates and minor EKG changes of the recovery days might be due more to the overexertion, when in a poor state of muscle training, than to the state of training itself.

In analysing the possible mechanisms by which the beneficial effect of the CVCS might have been exerted, as evidenced in the preservation of orthostatic tolerance and ability to walk upstairs without excessive cardiac acceleration, we are forced to regard venous compliance as the paramount physiological parameter of those we were able to measure. As has been pointed out (Figure 24), venous compliance during the 2-week CVCS experiment rose when suit pressurization was inadequate in duration or magnitude, and fell sharply as soon as the periods of full pressurization increased beyond a critical limit. This evidence, together with the large increase in compliance during the control experiment, suggests very strongly that the preservation of orthostatic tolerance in the CVCS experiment results from the maintenance of venous compliance at a suitably low value through the action of the suit when pressurized. This action can be identified as the creation of a pattern of distending forces within the vascular system (particularly in the capacitance system) which preserves the integrity of those anatomical elements and reflexes whose normal function is to compensate for gravity influences on the circulation when man is erect at 1G.

The idea that an increase in compliance is responsible for loss of orthostatic tolerance, is presumably not new. The evidence of Newberry and Bryan (ref. 6), based on 11 subjects and a standardized circulatory stress, which relates inter-individual differences in time to faint to venous compliance, is fairly conclusive in establishing a direct dependency. Under their conditions, fainting occurred in 3.2 minutes in their "weakest" subject, whose venous compliance index was 5.88% and in 16.2 minutes in the "strongest", whose index was 2.41%. In other words stress tolerance decreased to one fifth when venous compliance index increased to only 2.4 times the lowest observed value, within this group. Their index is a volumetric one defined as per cent change in arm volume at a venous impeding pressure of 30 mm Hg. For our subject, the increase in this venous compliance index during hypodynamic exposure was from 3 to 10% in the control experiment and from 3 to 3.6% in the CVCS. The change in predicted time to faint, according to Newberry and Bryan's data, for the control experiment would be from about 7 minutes before the 2-week exposure to about 1.5 after; they mention that general health appears to influence the venous compliance, and time to faint changes accordingly in an individual.

If venous compliance is in fact the key to orthostatic tolerance, and orthostatic tolerance is the primary measure of cardiovascular responsiveness, it is not difficult to appreciate the unique characteristic of the CVCS as a treatment to prevent deconditioning. This feature, we suggest, is the distribution of distending forces throughout the vascular tree so that each individual part of the system is loaded in essentially the same manner it would be when the wearer is erect under normal gravity conditions. Those veins and venules which are most severely distended when the suit is fully pressurized are the ones which are designed and adapted to withstand this kind of loading repeatedly and for long periods; the vessels which normally support only a moderate transmural pressure are similarly loaded by the CVCS. The action can be viewed as a straightforward exercising of the musculature contained in the walls of the veins; veins with heavily muscled walls are exercised severely and those with relatively weak muscles receive gentler loading by the suit. In contrast, treatments and devices which divide the body into high pressure and low pressure regions, such as limb cuffs or lower body negative pressure apparatus, subject some veins to lesser transmural pressures than they normally sustain, and some to excessive levels relative to their "design value", while providing no loading on the vasculature which is central to the pressure barrier.

Tolerance for high suit pressures.--The contrast between our experience and our expectations with respect to deleterious effects of suit pressurization deserves some comment, in the light of fears which were expressed regarding safety when the CVCS concept was first put forward. In preparing the pressurization system we were concerned that the high breathing pressures, creating moderate to high transmural pressures in the vascular system (relative to those typically experienced in pressure breathing without full or complete counter-pressure coverage) would place definite limits on the tolerable duration of the periods of suit pressurization during the CVCS experiment. As has been mentioned, and as illustrated in Figures 26 and 27, no such limitations were encountered. Pressurization duration was determined almost exclusively by superficial comfort factors, primarily the problem of discomfort from the tight helmet-restraining straps which passed through the crotch. At no time did the subject report symptoms suggesting inadequate venous return or any form of circulatory embarassment. As indicated by references to the hazards of orthostatic hypotension, particularly during sleep, in the original NASA specification, the project sponsors shared our concern about the long term consequences of suit pressurization. It appears that the circumstances of our experiment and those of "parade-ground faint" are different, in spite of an identity in transmural pressures. This may be related to the importance of the "creep" or stress relaxation property of veins, as described by Alexander, (ref. 10) and the means by which creep is corrected within the body.

CONCLUSIONS

The evidence from these preliminary experiments strongly supports the conclusion that a few hours per day of activation of the cardiovascular conditioning suit (CVCS) prevents the loss of orthostatic tolerance which otherwise results from prolonged bed-rest and immersion. In addition, use of the suit appears to reverse the trend of deterioration which develops in the first few days of such exposure to a hypodynamic environment, judging from the evidence provided by measurements of venous compliance in the forearm during 5 days when the magnitude and duration of suit pressurization was substantially less than the 2 to 4 hours adopted in the final week.

The venous compliance data suggest that 5 days or less of the combined bed-rest and immersion regime might produce as severe a loss of orthostatic tolerance as 14 days, and also imply that one or two days of CVCS usage might correct or eliminate the deterioration produced by an extended period of untreated exposure to simulated weightlessness.

The fact that total relaxation and sleep, while the CVCS was fully pressurized, produced no obvious signs of circulatory embarassment nor subjective symptoms of distress, has focused attention on the basic question of how the suit exerts its effects to prevent or counteract the de-conditioning of bed-rest and immersion. Considerably more work will be needed before a categorical answer is possible, but we have arrived at a working hypothesis which holds that the protective action results from the exercising of the venous musculature in a uniquely appropriate manner, which is reflected in maintenance or reduction of the venous compliance as measured in the elevated forearm.

While the evidence is far from conclusive, there appears to be a difference, in kind rather than of degree, between the immersed or weightless state and the normal 1G state at identical transmural pressures. If confirmed and explained, this difference may have far-reaching significance to the whole spectrum of space-protective garment design, emergency decompression survival, and related subjects.

Confirmation of the findings in this experiment in additional subjects and successful testing of the hypotheses arising from the present results should enable the early development of a simple and economical garment suitable for general space flight which will produce equivalent results to the experimental CVCS.

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February 1, 1968

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NASA-Langley, 1968 —— 5